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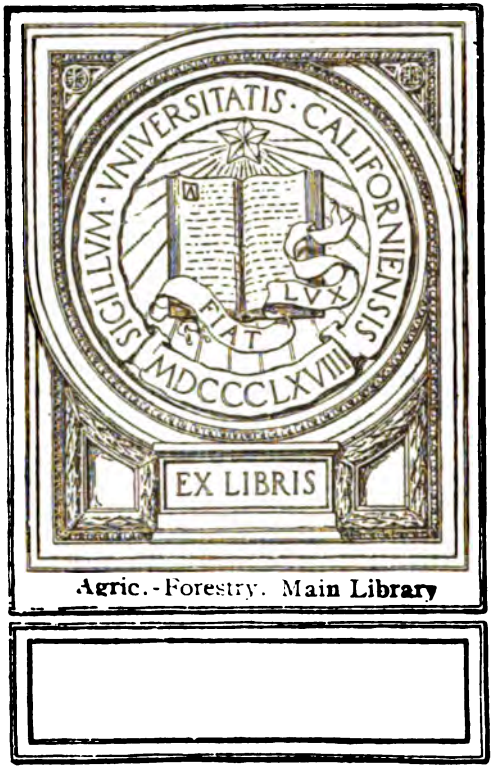

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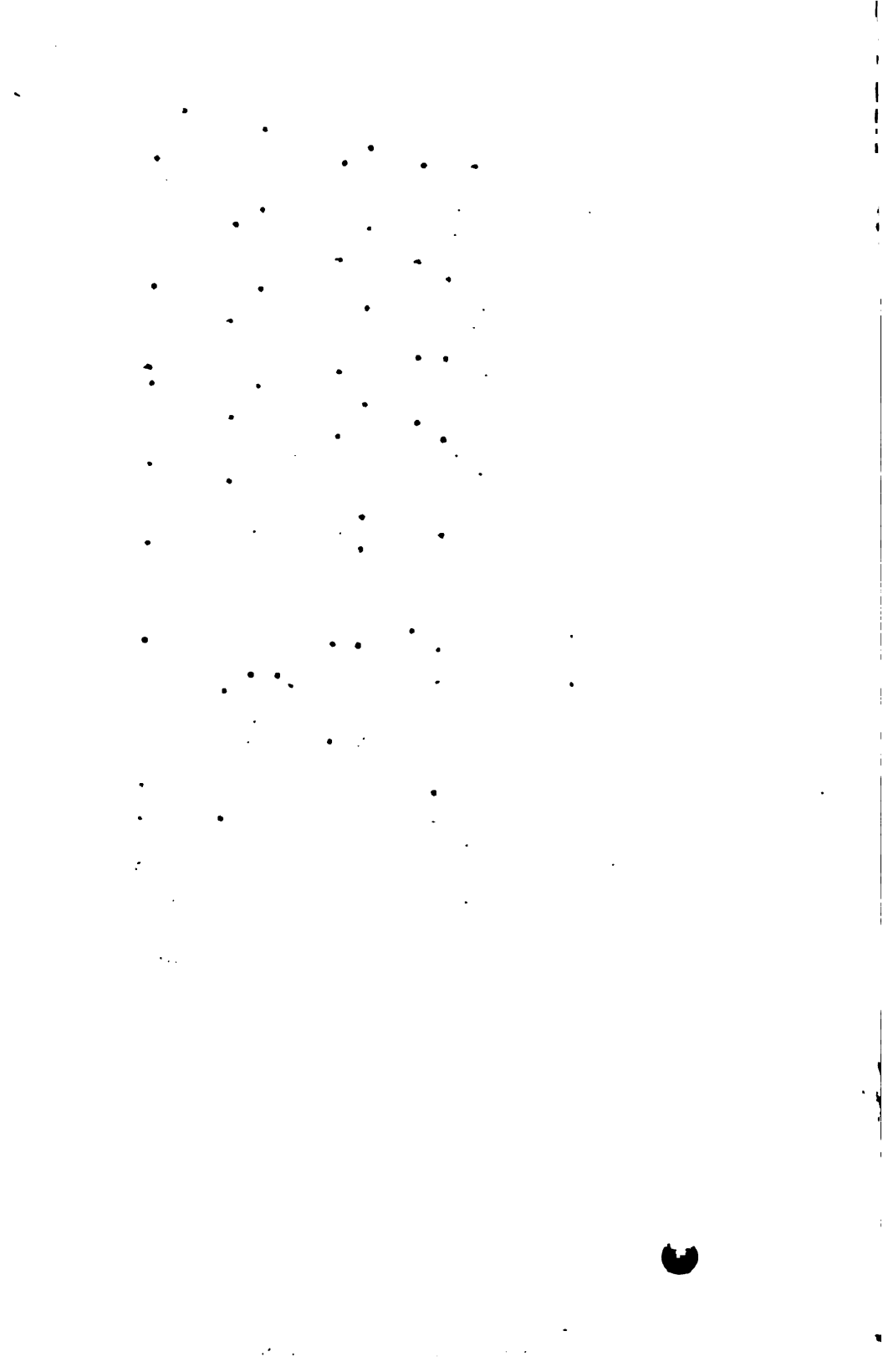

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BULLETIN NO. 59

"An Account of Some Features of the Climate of Reno, Nevada"

BY S. B. DOTEN

RENO, NEVADA, JUNE, 1905

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CLIMATE OF RENO

S. B. DOTEN

Moisture laden winds from the Pacific Ocean deposit their rain and snow upon the long western slopes of the Sierra Nevada mountains and upon their summits. Immediately east of the mountains, the valleys, however rich the soil, are covered with sagebrush and appear like barren deserts except where some stream overflows its banks and creates natural meadows, or where the land has been cleared and irrigated.

The geographical situation of the town of Reno is as follows: It is located in latitude 39 deg, 30 min., longitude 119 deg. 39 min. at an elevation of 4497 feet. It is in the western portion of the Truckee meadows near the foot-hills of the Sierra Nevada mountains which rise abruptly west and southwest of the city. It is in the beginning of the sagebrush desert country which extends east of Reno to Utah. The city is therefore located well within the rain-shadow of the Sierra.

This peculiar geographical situation accounts for the characteristic features of the local climate. The intervening mountain wall of the Sierra receives nearly all the moisture from the Pacific breezes. This makes the rainfall very low. To the north, south and east stretch the hot wastes and barren hills of the desert, and this tends to make the temperature high and the air dry and bracing.

Clear air, free from smoke and dust and moisture, holds heat poorly. At night the heated earth radiates its heat into the atmosphere and cools rapidly. For this reason, though the thermometer may register 98 degrees on a summer afternoon at Reno, it will often fall below sixty degrees before the following morning.

Over the desert the heated air rises and is replaced by cooler breezes from the mountains. On summer afternoons, the air flows into the Truckee Valley from the Sierra in brisk breezes which are characteristic of our climate.

In the vicinity of Reno, then, the climate is characterized by low rainfall and snowfall, warm, dry summers and open winters, brisk westerly winds, and hot summer days followed by cool nights.

RECORDS KEPT

From the year 1888 up to the present time, the University has kept a record of the most important features of the local climate. A portion of this record is herein presented in a condensed form and published as a bulletin of the Experiment Station because of its importance to the farmers of this vicinity.

It is easy for a trained mind to extract facts of value from tables of figures which bewilder the average man; so while these records are of interest to scientists, the primary aim of this bulletin is to present them in such a form that their value to the farmers will be as great as possible. Each table of figures, then, will be accompanied by a brief discussion which will point out facts of interest and make clear their importance.

TABLE I.

Average Temperature By Months and Years.

In this irrigated section of the semi-arid west, the temperature of the air is of the utmost importance; there is always too little summer rain to count for anything; the heat of the air helps to determine the amount of water used in irrigation and the rate of plant growth. We present, therefore, first the table of average temperatures from 1888 to 1904.

This record shows many facts of interest. In the averages for January, for instance, we find in January 1890 an average monthly temperature below 20 degrees; for January 1900, an average of nearly 40 degrees. The average of sixteen Januaries is midway between the two at about 30 degrees. The record for February is equally variable; that for July, much more constant.

In Table I. the variable averages of different years are equally interesting; the whole year 1897 averages five degrees below the year 1889. The reader will find many other facts of interest in this table.

TABLE I.

Average Temperature by Months and Years.

Years.	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Mean
January	27 5	28 5	19 6	32.8	34.0	32.3	30.9	28.8	36.9	30.4	22.2	.	39.8	30.8	30.1	34.2	31 8	30 7
February	42 7	35 4	30.9	33.3	40.4	31.9	30.0	42.2	37.9	27 8	39.	. .	40.2	30.3	39 6	20.1	38.0	35 0
March	42 4	44.9	39 6	39.8	41 4	40.2	39.1	40.5	39.8	32 2	36.3	38.4	46.5	39.2	33.6	40.5	40.5	39.7
April	40 0	52.2	49.0	56 0	44.8	42.0	50.5	47.6	37.2	48.4	50 8	49.0	45 2	45 2	45.8	43.7	46.2	46 7
May	56 6	56.7	57.3	53.6	58.3	50.2	57.0	53.9	47.2	58.4	51.7	49.7	55.6	54.4	. .	54.0	56 0	54.4
June	60.0	69.6	61 7	60.0	62.1	59.0		61.0	64.6	58.4	68.9	63 6	66	60.7	66.4	63.	64.0	63.1
July	70.6	74.4	72 6	68 4	71.0	66.8	72.9	67.2	70.9	67.3	70.2	69 6	70.0	70.4	67.2	65.0	68 3	69 6
August	72 0	72.4	68 7	71.2	72.8	68 6	75.7	66.5	66.9	69.6	69.4	62.7		69.2	67.2	67 3	70 2	69 4
September	67 4	61.3	63 8	59.1	62.8	55.2	60 4	57 0	58.9	56.9	61.0	64.2	55.8	58.0	62.6	60 0	61.8	60 3
October	53.8	50.4	50.0	51.6	47.8	47.7	52.2	53 3	52.4	47.6	47.3	47.4	49.4	53.2	50.7	53 9	49 5	50 5
November	39 8	53.1	36.5	43.5	41.7	38.3	43.2	38.0	38.8	41.9	40.2	43.0	43.6	43 8	38.8	44.0	43.0	41.8
December	37.0	32 3	32.3	30.0	34.4	36.1	30 0	31.2	37.3	31 6	29.1	31.5	34.6	35 2	36.4	33.1	34.0	33.2
Average for Year	50 8	52 6	48 5	49 9	50 8	47.4		48 9	49 2	47 5	48.8	...	....	49.2	.	48 3	50.3	49.9

TABLE II.

Highest Temperature By Months and Years.

Table II. shows the highest temperature which occurred in each month for seventeen years at Reno. In December, January and February the reader will note temperatures above 60 degrees; in July and August he will find two records of 100 degrees, the highest ever recorded on the University Hill. This table shows, too, how different years vary in their extremes of heat.

If the air were moist, such extremes of heat as those shown in Table II. would be unbearable. As it is, the air is so dry that, though the mercury may register from 90 to 100 degrees every afternoon for a week, there is in seventeen years no record of a single case of prostration by extreme heat or of sunstroke.

TABLE III.

Lowest Temperature by Months and Years.

Table III., seventeen years' record of lowest monthly and annual temperatures, shows the curious variability which is characteristic of our climate. A glance at the record of lowest temperatures for January shows in 1888, in 1890 and in several other years, temperatures far below zero. In January 1896 and January 1900 the minimum remained throughout the month well above the zero mark. The February record of lowest temperatures is of equal interest. There is one record below zero in March, and in ten years out of seventeen we find winter temperatures below the zero mark.

April's record of lowest temperatures is a record of severe frosts. The figures for May show frost for every year except 1894 and 1898. The record of lowest temperatures in June is of evident interest.

Compare Tables II. and III., the highest monthly temperature with the lowest. This comparison brings out many interesting facts. For July 1889 we find highest 100, lowest 45, a difference or range of 55 degrees in the one month. In July '96 we discover an absolute range of 60 degrees, from 39 to 99. Still these records show no frost in either July or August. Taken together these tables show great monthly changes in temperature; but in the summer months the daily changes are of equal interest.

TABLE II.

Highest Temperatures *(Absolute Maxima)* by Months and Years.

	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04
January	63	53	49	53	54	60	55	57	60	52	53	....	60	51	62	59	60
February	....	64	59	54	61	56	59	62	65	58	66		66	54	62	44	60
March	76	73	64	64	70	73	71	66	68	61	64	70	74	65	61	64	62
April	88	80	75	74	70	68	75	75	66	79	82	78	77	71	72	74	78
May	87	90	84	77	81	80	82	84	84	86	80	80	82	80	....	87	84
June	86	93	90	90	91	86	85	93	89	89	90	93	93	95	91	94	92
July	92	100	96	95	93	95	96	93	99	93	99	98	96	97	96	90	93
August	93	94	94	96	93	94	100	97	92	94	98	85	...	93	96	93	95
September	93	91	86	92	90	86	84	87	86	82	89	90	86	88	94	93	90
October	83	86	76	77	82	76	74	80	82	74	74	78	75	80	76	81	77
November	69	65	68	72	70	65	70	66	69	71	70	66	69	73	65	70	67
December	60	52	62	52	63	60	47	63	60	59	55	60	56	56	68	66	58
Highest for Year	93	100	96	96	93	95	100	97	99	94	99	98	96	97	96	94	95

The daily range is best shown on the record of a thermograph, literally a thermometer which writes out a chart of every variation in the heat of the air. (Fig. 2).

Figure 2 is a photographic reproduction of such a chart. It is a fair weather record from June 12th to June 19th 1905. It resembles a series of mountains and valleys, the elevations standing for high temperatures and the depressions for low ones. It is this great daily range of temperature that makes the summer climate throughout Nevada so delightful. Warm, dry days are followed by cool nights. It is this same feature, however, which is most dangerous to crops, for it causes late frosts in the spring and early ones in the autumn.

TABLE IV.

Frost Table.

Table IV., the frost record, shows how many times the mercury has fallen to 32 degrees or below in each month of the growing season for the past seventeen years. This table gives an average of fifteen frosts per year in April, three in May and two in September. For the month of June the record shows four frosts in every ten years.

Temperature and rainfall are the two great climatic factors which determine what crops can be raised in any region. The temperature determines the length of the growing season, the amount of rainfall and its distribution through the year decides whether crops shall be raised with or without irrigation. The following rainfall table, then, is of peculiar interest.

TABLE V.

Precipitation of the Past Seventeen Years With Monthly and Annual Averages.

A glance at Table V., along the line of yearly totals, shows how variable is the total yearly fall of rain and snow.

In 1902, for instance, we find a yearly total of less than five inches of water; in 1893 but little more, in 1904 and in 1891 more than ten inches fell; while in 1890 there fell rain and snow which would amount to over 15 1-2 inches of water on the level. The annual average for the entire seventeen years is 8.20 inches, and this probably comes close to the average annual precipitation for this region.

TABLE III.

Lowest Temperature *(Absolute Minima)* by Months and Years.

	'88	'89	'90	91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04
January	-13	-1	-19	8	11	20	7	2	14	5	6	2	20	5	-1	-3	2
February	14	3	-4	8	6	9	0	24	12	-12	20	0	12	-6	10	11	9
March	13	19	12	13	16	13	12	14	14	-3	10	16	22	20	7	18	19
April	20	25	23	24	22	19	26	18	14	26	22	23	22	21	23	19	22
May	26	29	29	30	25	24	35	28	16	28	33	25	32	32	30	30	28
June	37	38	30	32	28	34	....	33	37	33	33	36	39	36	31	34	40
July	41	45	42	38	38	41	46	42	39	39	44	42	45	36	35	36	39
August	41	41	44	37	41	41	38	35	40	45	40	38		44	43	38	44
September	42	35	38	31	35	28	28	24	37	30	32	38	28	33	31	30	36
October	27	24	27	24	21	16	24	28	25	24	20	22	16	31	28	27	24
November	17	16	18	16	12	9	15	13	7	15	7	22	24	24	13	18	20
December	22	-7	12	-7	6	13	6	2	15	-4	7	13	9	8	12	9	11
Lowest for Year	13	7	19	7	6	9	7	2	7	12	6	0	9	-6	-1	-11	2

In this same table the column of monthly means shows the distribution of rainfall throughout the year. With the exception of the month of May, the precipitation decreases steadily month by month, from January to July. Table I. shows that January is the coldest month; Table V. shows that in January there falls the greatest amount of rain and snow. As the heaviest snowfall occurs in the coldest month the snow in the mountains usually has several months in which to be drifted into canyons and into sheltered places among rocks and trees. This record of rainfall gives July the least precipitation and August much more. Eleven July records out of seventeen show no rain at all or only a trace. Three records for August out of sixteen are rainless.

The May record is very peculiar in many respects. It will be noted that in May '91 there was the greatest precipitation for that year. More rain falls here in May than in March or April; in fact, May ranks next to December in the matter of precipitation.

Table V. gives the whole amount of water which falls in each month; Table VI. shows how much of it falls in the form of snow.

TABLE VI.

Snowfall In Inches For Seventeen Years.

The bottom line of totals gives but an inch of snow for the year 1900 and over seven feet for 1890, with a yearly average of nearly two feet. This yearly average is somewhat misleading. Two feet of snow distributed through the winter and early spring in squalls and flurries will not usually mean much snow on the level at any one time. The table tells of snow in May and traces of it in June and July.

TABLE VII.

Number of Days in Each Month When There is .01 of an Inch or More of Rain or Melted Snow.

Another idea of the rainfall and snowfall may be gained from Table VII. which gives the number of rainy days in each month and each year, that is, the number of days on which there fell rain or snow amounting to the hundredth part of an inch of water on the level. We find six such days in January, one in July, 43 for an average year.

Now it is easy to see that while temperature and rainfall are the primary factors in deciding what crops shall grow in a given

Figure IV.—The Pogonip or Frost Fog.

TABLE IV.

Frost Table.

	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Means.
April	9	5	10	—	19	20	—	17	24	13	12	8	16	19	15	17	16	15
May	—	5	2	2	7	13	—	3	12	2	—	13	1	3	—	3	3	3
June	0	0	2	-	4	0	—	0	—	0	0	0	0	0	1	0	0	0.4
July	0	0	0	—	0	0	0	--	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	--	0	0	0	0	0
September	0	0	0		0	5	4	5	0	3	1	0	1	0	2	2	0	2

This record shows the number of times frosts have occurred in each of the above months.

region; yet these conditions depend largely upon the clearness or cloudiness of the atmosphere.

TABLE VIII.

Clearness and Cloudiness.

The table of clearness and cloudiness is of greatest interest in the line of totals and in the final column of averages. These show 195 clear days for the average year, 106 days partly cloudy and 64 cloudy ones. About 4-7 of each year is cloudless. In June there is an average of three cloudy days, in July one and in August two. Even in January there are but eight days when the sky is wholly overcast.

It is in respect to temperature and rainfall that the University has kept the completest and most valuable records. The eight tables presented in this pamphlet deal with these aspects of our local climate, they are the condensed results of 204 monthly records. In these tables two facts are prominent, that our annual mean temperature is 49.9 degrees and that our annual mean precipitation equals 8.20 inches of water.

Now while rainfall and temperature are the most important phenomena of our local climate, there are many other conditions of the atmosphere whose changes are of interest. Among these are the humidity of the air, its motion, its clearness, its electrical condition and changes in its pressure.

The records taken at the University include a long series of barometic observations, but these are not published here because their principal use is in the prediction of coming changes in the weather.

Among the records for the summer months, thunder storms are often mentioned and there are recorded many instances of slight damage to trees and telegraph poles by lightning; but there is no mention of any serious damage to property by lightning or of loss of life from this cause.

High winds from the west are common, still, though the wind has occasionally reached a velocity of over sixty miles an hour in winter storms, there is no record of any serious damage to property. In the heaviest wind storms some windows have been broken and other minor damage has occasionally been done by the wind. In February 1904 some flimsy buildings were blown down in the town of Sparks.

Over the Truckee Meadows in which the town of Reno is located the air is so free from smoke, dust and fog that here as in all the western states, objects are clearly visible at a long distance. The frontispiece of this pamphlet shows two snowy peaks of the Sierra Nevada standing out clearly on the sky-line at a distance of fifteen miles with other snowy mountains not less than twenty-five miles away. Figure 2 is a photograph of one of these peaks taken with a long-focus lens as an illustration of the remarkable clearness of the atmosphere in this vicinity.

Among the weather records at the University there is an incomplete record of the humidity of the air, complete enough, however, to indicate the small amount of moisture which it contains and to explain why temperatures of from 80 to 100 degrees are borne here with ease. In the winter the air may become more humid, so charged with moisture in fact, that at low temperatures it is condensed into a thick fog which freezes on everything out of doors in white crystals.

THE POGONIP OR FROST FOG.

This frost fog is the pogonip, a peculiar and interesting phenomenon which may occur in any of the cold months from November to the middle of March. It is most common in December, January and February, often appearing early in the morning and disappearing again before noon. At times, however, when there is no wind the pogonip may linger in the valley for days together, hiding the sun and shrouding everything in a white coat of frost. Then telegraph wires become snowy ropes. Every twig of every tree is heavy and white with crystals. Even last year's cobwebs become a dainty lace of frost.

In the midst of a pogonip one may leave the valley and climbing up the mountain side come out above the fog into brilliant winter sunshine and a cloudless sky. The pogonip is far below in the valley a sea of cloud breaking in white billows along the mountain slopes.

CONCLUSION

The University is now taking continuous records of the temperature and pressure of the air; the velocity of the wind, the rainfall and other atmospheric phenomena. At an early date we hope to publish exact information about those factors of our climate which are not recorded in this pamphlet.

TABLE V.

Precipitation of the Past Seventeen Years with Monthly and Annual Averages.

	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Means.
January	1 72	0 37	6.71	0.06	0.58	1 46	0.89	2 81	2.87	1 05	0.99	1 12	0.50	2.48	0.15	3.00	0 21	1 59
February.....	T.	0.29	3 91	2.69	1.40	1.45	1.42	0.33	T.	2 10	1 47	0 65	0.27	3 24	1.40	1 00	4 99	1.57
March..	0.57	0 65	0 39	2 28	0.76	0.58	0.22	0 07	1 15	0 72	0 65	1.03	0 59	0 39	1.73	0.53	2.12	0 85
April.	0 14	0.03	0.30	0 56	0 09	0 38	0 10	0 39	1 31	0 03	0.41	0 21	1.75	0 32	0.10	1 04	0.35	0 44
May.....	0 79	1.82	1 44	2.72	0 22	0 13	0 91	0 57	1.66	1.73	0 95	0 41	0.39	1.60	T.	0 14	0 25	0 93
June.	0.11	T.	0 01	0.41	1 27	0 00	1.06	T.	T.	0 29	0 00	0 40	1 08	T.	0 00	0 22	T.	0.29
July.....	0 45	0 00	0 00	0 00	T.	T	0.31	0 00	1 03	T.	0 00	0 22	0 18	T	0 25	0 00	T.	0.14
August.....	0 27	0 00	0 16	T.	0.00	0 04	0.12	0 02	0 79	0.07	0.16	1.37	--	1.60	0 42	0.01	0 29	0.33
September....	0 70	0.00	0 87	0 54	0.07	0 24	0 19	0 24	0 93	0.02	0.31	T	0.67	0.09	0 09	0 00	0.71	0 33
October.....	0 00	0 36	0 05	T	0.27	0 02	0 16	0 10	0.08	0 96	0.24	0 72	0 44	0.51	0.10	0 15	1 08	0 31
November....	1 95	1 74	0 00	T.	4 65	0 42	0.02	0 17	0.89	0 16	0 63	0.47	1.48	0.68	0.50	0 31	0 00	0.83
December ..	0.70	2 30	1 69	1.14	2.61	0 32	1.88	0 83	0 31	0 87	0.60	1.69	0.46	0 45	0 20	0.15	0 63	0.99
Totals..	8.06	7.56	15.53	10 40	11 92	5.04	7.28	5.53	11 02	8.00	6.41	8.29	7 81	11 36	4.94	6 55	10.63	8 20

| | | |

TABLE V.

Precipitation of the Past Seventeen Years with Monthly and Annual Averages.

	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Means.
January	1 72	0 37	6.71	0.06	0.58	1 46	0.80	2 81	2 8[illegible]									
February....	T.	0.29																
March..	0.57	0.05																
April.	0 14	0.03																
May.....	0 79	1.82																
June.....	0.11	T.																
July.....	0 45	0 00																
August.....	0 27	0 00																
September....	0 70	0.00																
October.....	0 00	0 36																
November....	1 95	1 74																
December ...	0.70	2 30																
Totals..	8.06	7.56	1															

TABLE VI.

Snowfall in inches for Seventeen Years.

	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Means.
January	4	4	54	*T*	5	4	3	15	1	6	10	*T*	*T*	13	*T*	12	1	7 7
February	*T*	3	20	10	12	3	8	*T*	*T*	23	1	0	*T*	27	4	7	5	7 2
March	8	*T*	3	4	2	1	1	0	2	6	6	4	1	3	..	..	0	2 7
April	1	*T*	1	*T*	*T*	1	*T*	0	0	1	2	1	*T*	*T*	*T*	0	*T*	0.4
May	0	2	*T*	0	*T*	0	0	*T*	0	0	..	2	0	0	0	1	0	0 3
June															*T*			
July															*T*			
August																		
September											*T*							
October				*T*	*T*						*T*		*T*					
November	0	*T*	0	0	*T*	*T*	0	1	0	0	0	2	0	1	0	0	0	0 2
December	2	25	10	2	..	*T*	12	3	0	1	0	5	0	*T*	*T*	*T*	*T*	3 8
Totals	15	34	88	16	19	9	24	19	3	37	19	14	1	44	4	20	6	22 3

TABLE VII.

Number of days in each month when there was .01 of an inch or more of rain or melted snow.

	88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Means.
January	8	3	11	2	5	4	6	8	9	6	5	6	3	10	4	4	3	6
February	0	3	7	9	7	5	3	2	0	9	5	2	1	12	8	7	12	5
March	3	5	8	7	5	5	5	2	8	5	7	6	1	4	..	7	8	5
April	2	1	6	3	3	4	2	2	5	1	3	2	6	5	4	1	1	3
May	.	6	5	14	4	2	5	3	6	5	..	3	6	5	..	3	2	5
June	3	0	1	9	2	0	3	0	0	2	0	1	5	0	0	5	0	2
July	7	0	0	0	0	0	4	0	7	0	0	0	3	0	3	0	0	1
August	2	0	4	0	0	1	4	1	6	2	0	3	..	3	5	1	5	2
September	5	0	5	6	2	2	2	1	4	1	1	0	4	1	2	0	7	3
October	0	6	1	0	6	1	2	1	3	5	4	2	5	3	3	2	9	3
November	8	5	0	0	6	3	1	1	4	2	3	5	6	3	3	5	0	3
December	7	16	6	7	4	2	10	4	1	5	.	7	4	5	3	3	3	5
Total for Year		45	54	57	44	29	48	25	53	43		37		51		38	50	43

TABLE VIII.

Clearness and Cloudiness.

	1888			1889			1890			1891			1892			1893		
	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.
January. ...	9	4	18	19	12	0	11	11	9	14	16	1	19	7	5	8	12	11
February ...	17	9	3	17	8	3	12	12	4	15	7	6	12	10	7	8	11	9
March.	12	10	9	15	11	5	13	11	7	12	10	9	8	15	8	8	10	13
April.....	23	4	3	12	14	4	17	12	1	11	10	9	10	12	8	12	7	11
May..... ..	21	6	4	21	8	2	17	9	5	11	12	8	18	7	6	15	11	5
June.	14	14	2	22	8	0	21	9	0	18	6	6	20	7	3	29	1	0
July.....	19	12	0	30	1	0	23	8	0	27	4	0	27	3	1	27	2	2
August	28	3	0	29	2	0	17	12	2	27	3	1	25	4	2	26	3	2
September..	20	10	0	23	5	2	18	7	5	..	..	..	..	..	..	15	7	8
October. ..	29	2	0	11	13	7	22	6	3	22	6	3	14	10	7	20	6	5
November ..	17	6	7	15	7	8	23	7	0	18	7	5	6	15	9	12	3	15
December...	10	12	9	5	8	18	12	9	10	7	10	14	7	13	11	12	9	10
Averages ..	219	92	55	219	97	49	206	113	46							192	82	91

TABLE VIII. *(Continued.)*

Clearness and Cloudiness.

	1894			1895			1896			1897			1898			1899		
	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.
January	7	12	12	8	9	14	4	16	11	7	19	5	17	8	6	15	6	10
February ...	10	7	11	..	..	.	16	11	2	10	10	8	16	6	6	13	11	4
March	8	5	18	9	21	1	9	13	9	12	16	3	20	7	4	4	16	11
April	19	4	7	8	17	5	6	12	12	17	12	1	21	7	2	20	2	8
May	13	7	11	10	16	5	10	14	7	12	19	0	..	..	..	15	8	8
June	14	6	10	23	4	3	24	5	1	16	6	8	20	5	5	24	2	4
July.....	21	9	1	26	0	5	16	11	4	29	1	1	25	6	0	18	20	0
August.....	18	13	0	22	7	2	15	12	4	20	8	3	..	..	..	18	10	3
September..	20	8	2	21	5	4	15	12	3	21	6	3	23	4	3	25	4	1
October	15	14	2	24	0	7	19	12	0	18	6	7	22	3	6	13	12	6
November..	14	15	1	10	13	7	12	13	5	14	12	4	14	7	9	9	12	9
December..	2	18	11	6	16	9	15	14	2	13	13	5	..	..	..	9	9	13
Averages...	161	118	86				161	145	60	189	128	48	..	..	..	176	112	77

TABLE VIII. *(Concluded).*

Clearness and Cloudiness.

	1900			1901			1902			1903			1904			Monthly Averages.		
	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.	Clear.	P. Cl.	Cl'dy.
January	16	8	7	11	14	6	11	10	10	18	10	3	25	4	2	13	10	8
February ...	13	10	5	4	7	17	6	10	12	17	10	1	7	10	12	12	9	7
March . ..	12	12	7	11	12	8	..	..	..	12	12	7	7	8	16	11	12	8
April..... .	9	11	10	11	14	5	8	8	14	22	6	2	15	6	9	14	9	7
May	15	11	5	12	8	11	..	..	..	18	10	3	23	4	4	15	10	6
June	20	8	2	17	8	5	20	7	0	21	7	2	23	7	0	21	6	3
July..	28	1	2	23	7	1	17	11	3	28	3	0	20	11	0	24	6	1
August.....	..	..	..	26	2	3	19	10	2	27	3	1	12	18	1	22	7	2
September..	14	12	4	22	6	2	25	5	0	25	2	3	17	7	6	20	7	3
October ...	11	10	10	16	8	7	19	10	2	20	9	2	18	5	8	18	8	5
November..	8	13	9	12	7	11	16	10	4	14	9	7	12	13	5	13	11	6
December ..	16	11	3	13	10	8	14	14	3	23	7	1	16	7	8	12	11	8
Averages ..				178	103	84				245	88	32	195	100	71	195	106	64

STATE UNIVERSITY OF NEVADA

AGRICULTURAL EXPERIMENT STATION

BULLETIN No. 60

"THE WEATHER FOR 1905"

By S. B. DOTEN

RENO, NEVADA, APRIL, 1906

University of Nevada

Agricultural Experiment Station

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Annual summary for 1905	Temperature						Precipitation (in inches)					Number of Days			
	Highest	Lowest	Average for Month	Average daily range	Normal	Departure from Normal	Rainfall	Snowfall	Total	Normal	Departure From Normal	Clear	Partly Cloudy	Cloudy	Rainy or Snowy
January	60	16	38	23	31	-|- 7		0.12	0.12	1.59	—1.37	14	15	2	1
February	64	8	36	23	35	-|- 1	1.29		1.29	1.57	—0.28	11	6	11	4
March	66	12	43	24	40	-|- 3	0.92	0.19	1.11	0.85	-|-0.26	10	8	13	7
April	72	25	48	29	47	-|- 1	0.91	0.55	1.46	0.44	-|-1.02	14	14	2	4
May	79	29	50	25	54	—4	0.36	0.35	0.71	0.93	—0.22	9	14	8	5
June	88	35	61	32	63	—2			0.00	0.29	—0.29	26	4	0	0
July	98	45	72	36	70	-|- 2	0.05		0.05	0.14	—0.09	30	1	0	0
August	96	46	69	36	69	0	0.32		0.32	0.33	—0.01	26	4	1	1
September	90	31	61	33	60	-|- 1	0.10		0.10	0.33	—0.23	20	8	2	1
October	81	21	49	33	50	—1	T.		T.	0.31	—0.31	30	1	0	0
November	67	16	38	27	42	—4			0.45	0.83	—0.38	17	9	4	7
December	51	7	29	25	33	—4			0.08	0.99	—0.91	15	11	5	2
For the year	98	7	49.5	29	49.9	—0.4			5.69	8.20	—2.51	222	95	48	32

THE WEATHER OF 1905

S. B. DOTEN

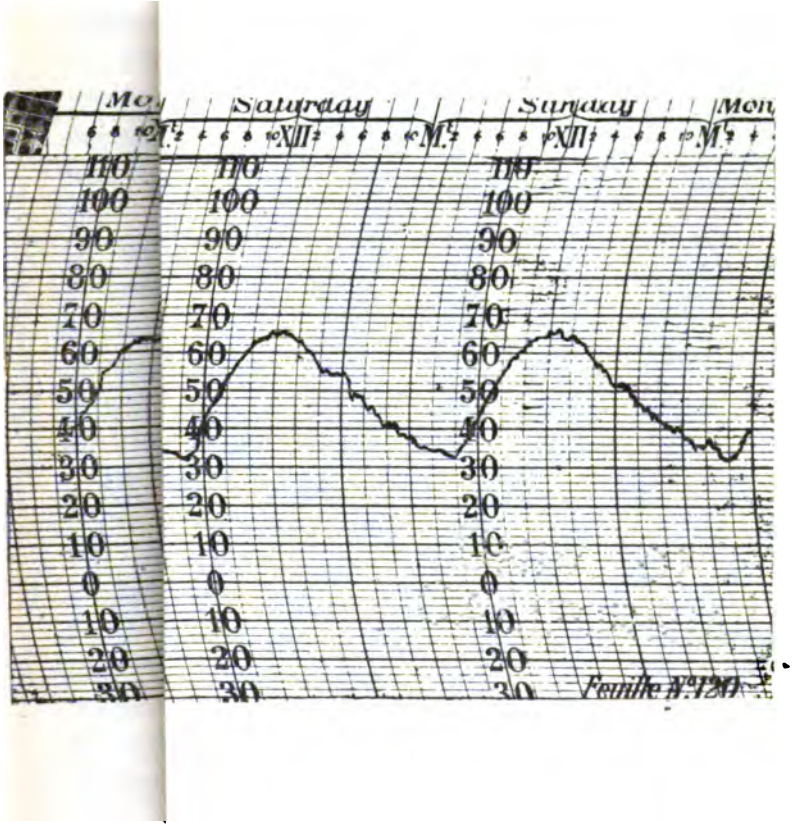
In presenting this meteorological summary for 1905, the University issues the last portion of the records which have been kept continuously for eighteen years. In Bulletin 59 these records were published in the form of tables from which averages were deduced. The present bulletin gives an account by months of the weather conditions during the past year, together with an annual summary in which the records for 1905 are compared with the averages of conditions during the preceding seventeen years.

On January 1st, 1906, the University ceased taking meteorological records and the recorded observations for eighteen years previous were turned over to the U. S. Weather Bureau which has recently established an office in Reno. While no further observations will be taken at the University, instruments will soon be installed on the Station Farm near Reno and upon the State Experiment Farm in Lincoln county, where the records will be of the utmost interest to the Weather Bureau and to farmers in that vicinity. The meteorological work now in progress on the summit of Mount Rose, fifteen miles south of Reno, at an altitude of 10,800 feet, will be continued and its scope enlarged and extended. This work is under the direction of Dr. J. E. Church of the State University, a member of the Sierra Club and an enthusiastic mountaineer, to whose heroic ascents of the mountain in mid-winter we owe much information of scientific interest and importance.

TEMPERATURE.

The annual summary on the first page of this bulletin brings out some intersting facts. In January, for instance, the highest

temperature is sixty degrees. Only once in eighteen years has there been a higher record in January. The average for the month is seven degrees above the normal. The snowfall, however, in sharp contrast to this excessive temperature, is more



ing to a point between 60 and 70 degrees every afternoon.

Such long periods of clear weather are not unusual features of our winter climate. For weeks together the sky will be cloudless; and, seen through the clear air of this high plateau, distant mountains stand out in the sunshine in brilliant white against the blue. The rainfall for March and April was above the usual average, almost enough so to make up for any deficiency in January and February.

Through the remainder of the year, the records of heat and cold do not vary greatly from average conditions until Novem-

ber and December, which were each four degrees colder than the normal. The highest temperature recorded in 1905 was 98 degrees; the lowest, 7 degrees; the average for the year was 49.9 degrees, 0.4 of one degree below the normal.

An interesting feature of the annual summary will be noted in the column giving the average daily range of temperature; from which it will be seen that in the year 1905 there was an average daily variation in heat and cold of 29 degrees. This variation was greatest in the cloudless months of July and August when the temperature ranged daily through 36 degrees; least in January and February when the average daily variation amounted to 23 degrees. This great daily range of temperature is an important and characteristic feature of our climate.

In the spring it endangers the fruit crop; for warm, sunny days are followed by nights cloudless and cold when the frost plays havoc with bud and blossom. This makes fruit raising somewhat precarious on the plateau east of the Sierra and makes it exceedingly important that orchard sites shall be well chosen. A sunny hollow is the worst possible site; for warmed and sheltered during the day, it becomes at night a resting place for the coldest air of the region which slips down from the higher lands into the hollows where it stays until morning. Many of the best orchards in Western Nevada are located on the foothills just above the valleys. Such a position insures good air-drainage and makes a great difference in the amount of damage by frost.

A few feet of difference in elevation makes a surprising change in the temperature.. On the University hill temperatures of 36 to 42 degrees are usually accompanied by light frosts in the valley below. Frost is sometimes visible on alfalfa halfway up the hill when fifteen feet higher up the thermometeter stands at 40 degrees a few feet above the ground. All this illustrates the need of choosing for orchards, sites where the cold of the early morning will have the least injurious effect.

The great daily range of temperature certainly has its bad influences on agriculture in this vicinity, but it is equally cer-

tain that it forms in other ways one of the most pleasant and beneficial features of our climate. In summer the thermometer may stand for hours together between 90 and 100 degrees, yet the air is so dry that its heat causes little discomfort and cases of sunstroke are unknown. Toward evening the temperature moderates, and by morning it usually falls to a point 30 or 40 degrees below the reading of mid-afternoon.

PRECIPITATION.

In January and February the total fall of rain and snow was far below the average; in March and April it was almost as far above. From May throughout the remainder of the year there was a continual deficiency of rain and snow. The average precipitation for the preceding seventeen years was 8.20 inches. The total for 1905 was 5.69 inches, a shortage of almost one third; yet the year 1905 was not considered an especially dry year. This is probably due to the fact that the deep snow which accumulated in the higher mountains during February, March and April did not melt until late in the summer.

CLEARNESS AND CLOUDINESS.

In 1905 there were 222 clear days, 95 partly cloudy and 48 cloudy ones. On 32 days there fell rain or snow amounting to one one hundredth of an inch of water. Nearly two-thirds of all the days were cloudless. A little more than one-fourth were partly cloudy, while only about one-eighth of the days were cloudy. The average of seventeen years shows 195 clear days, 106 partly cloudy and 64 cloudy days. It is readily seen that the year 1905 had far more clear days and fewer cloudy ones than the average.

THE WEATHER BY MONTHS.

The following tables give a detailed account of each day's weather for each month of the year 1905. They present a fair example of climatic conditions in Western Nevada in a year somewhat dryer than the average:

Month of January, 1905; Station, Reno; County Washoe; State, Nevada.

Date	TEMPERATURE. Maximum.	Minimum.	R'nge	PRECIPITATION Time of Beginning	Time of Ending	Amount	Snowfall, in inches	Prevailing Wind Direction	Character of Day
1...	40	16	24	.....	.....	.....	.....	N. E.	Clear
2...	40	20	20	.....	.....	.....	.....	E.	P. Cl.
3...	53	20	33	.....	.....	.....	.....	N. E.	P. Cl.
4...	44	21	23	.....	.....	.....	.....	N.	Clear
5...	42	20	22	.....	.....	.....	.....	N. E.	Clear
6...	40	24	16	.....	.....	.....	.....	E.	Clear
7...	43	26	17	.....	.....	.....	.....	N. E.	P. Cl.
8...	48	27	21	.....	.....	.....	.....	N. E.	Clear
9...	43	28	15	.....	.....	.....	.....	N. E.	Clear
10...	41	18	23	.....	.....	.....	.....	N.	P. Cl.
11...	39	19	20	.....	.....	Trace	.....	W.	P. Cl.
12...	41	16	25	.....	.....	.....	.....	N. E.	Clear
13...	46	19	27	.....	.....	.....	.....	N. E.	P. Cl.
14...	53	29	24	.....	.....	.....	.....	N. E.	P. Cl.
15...	56	33	23	.....	.....	.....	.....	W.	P. Cl.
16...	48	34	14	.....	.....	.....	.....	N. E.	Clear
17...	50	33	17	.....	.....	.....	.....	N. E.	Clear
18...	48	24	24	.....	.....	.....	.....	N. W.	P. Cl.
19...	48	30	18	.....	.....	.....	.....	W.	P. Cl.
20...	51	28	23	.....	.....	.....	.....	W.	P. Cl.
21...	47	32	15	.....	.....	.....	.....	W.	P. Cl.
22...	51	38	13	Night	1 P. M.	0.12	.....	E.	Cloudy
23...	60	37	23	.....	.....	.....	.....	N. E.	P. Cl.
24...	60	34	26	.....	.....	.....	.....	W.	Clear
25...	60	31	29	.....	.....	.....	.....	W.	Clear
26...	54	23	31	.....	.....	.....	.....	N. E.	Clear
27...	60	23	37	.....	.....	.....	.....	W.	P. Cl.
28...	58	24	34	.....	.....	.....	.....	N. E.	Clear
29...	58	29	29	.....	.....	.....	.....	N. E.	Clear
30...	57	33	24	.....	.....	.....	.....	W.	P. Cl.
31...	52	35	17	.....	.....	Trace	.....	W.	Cloudy

MONTHLY SUMMARY.

Temperature.

Mean maximum 49.4
Mean minimum 26.6
Mean 38
Maximum .....60; date, 23rd
Minimum .....16; date, 12th
Greatest daily range .....37 degrees

Precipitation.

Total ..... 0.12 inches
Greatest in 24 hours ..0.12; date, 22nd

Snow.

Total fall, ... inches; on ground 15th
0 inches; at end of month, 0 inches.

Number of Days.

With .01 inch or more precipitation, 1;
Clear, 14; partly cloudy, 15; cloudy, 2.

REMARKS.

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Month of February, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	52	32	20	Night	7 P. M.	.52	.....	W.	Cloudy
2...	46	32	14	.....	.....	.....	.....	N. E.	Cloudy
3...	42	32	10	.....	.....	.....	.....	W.	Cloudy
4...	50	32	18	.....	.....	.....	.....	W.	Cloudy
5...	39	33	6	.....	.....	.....	.....	W.	Cloudy
6...	35	29	6	Night	8 A. M.	.23	.....	W.	Cloudy
7...	40	25	15	.....	.....	.....	.....	N. E.	P. Cl.
8...	42	21	21	.....	.....	.....	.....	W.	Clear
9...	46	20	26	.....	.....	.....	.....	W.	P. Cl.
10...	41	23	18	.....	.....	.....	.....	W.	P. Cl.
11...	31	23	8	.....	.....	.....	.....	W.	Cloudy
12...	29	8	21	.....	.....	.....	.....	E.	P. Cl.
13...	34	8	26	.....	.....	.....	.....	E.	P. Cl.
14...	34	11	23	.....	.....	.....	.....	E.	Cloudy
15...	42	14	28	.....	.....	.....	.....	E.	Cloudy
16...	35	20	15	.....	.....	.....	.....	E.	Cloudy
17...	44	28	16	.....	.....	.09	.....	E.	Cloudy
18...	54	26	28	.....	.....	.....	.....	W.	Cloudy
19...	58	29	29	4 P. M.	Night	.45	.....	W.	Cloudy
20...	56	29	27	.....	.....	.....	.....	E.	Clear
21...	57	27	30	.....	.....	.....	.....	W.	P. Cl.
22...	60	26	34	.....	.....	.....	.....	N. E.	Clear
23...	61	27	34	.....	.....	.....	.....	N. E.	Clear
24...	61	30	31	.....	.....	.....	.....	N. E.	Clear
25...	62	31	31	.....	.....	.....	.....	N. E.	Clear
26...	62	30	32	.....	.....	.....	.....	N. E.	Clear
27...	63	28	35	.....	.....	.....	.....	N. E.	Clear
28...	64	28	36	.....	.....	.....	.....	N. E.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 47.86
Mean minimum 25.07
Mean 36.45
Maximum ..... 64; date, 28th
Minimum ....8; date, 12th
Greatest daily range ..... 36 degrees

Precipitation.

Total ....1.29 inches
Greatest in 24 hours, ...; date, ...

Snow.

Total fall, ... inches; on ground 15th, 0 inches; at end of month, 0 inches.

Number of Days.

With .01 inch or more precipitation, 4;
Clear, 11; partly cloudy, 6; cloudy, 11.

REMARKS.

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Month of March, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	64	29	35	.....	.....	.....	.....	E.	Clear
2...	66	29	37	.....	.....	.....	.....	E.	Clear
3...	66	28	38	.....	.....	.....	.....	E.	Clear
4...	65	32	33	.....	.....	.....	.....	E.	Clear
5...	66	32	34	.....	.....	.....	.....	E.	Clear
6...	63	32	31	.....	.....	.....	.....	E.	Clear
7...	62	30	32	.....	.....	.....	.....	N. E.	Clear
8...	61	28	33	.....	.....	.....	.....	E.	Clear
9...	63	27	36	.....	.....	.....	.....	N. E.	Clear
10...	65	30	35	.....	.....	.....	.....	S. W.	P. Cl.
11...	54	31	23	.....	.....	.....	.....	S. W.	Cloudy
12...	57	35	22	1 P. M.	5 P. M.	.02	.....	W.	Cloudy
13...	54	39	15	.....	.....	.....	.....	W.	Cloudy
14...	57	30	27	.....	.....	.....	.....	S. W.	P. Cl.
15...	51	33	18	4 P. M.	.....	.13	.....	N. E.	Cloudy
16...	49	39	10	.....	.....	.22	.....	W.	Cloudy
17...	52	34	18	.....	.....	.....	.....	W.	Cloudy
18...	48	34	14	.....	8 A. M.	.26	.....	W.	Cloudy
19...	47	35	12	.....	.....	Trace	.....	W.	Cloudy
20...	59	30	29	.....	.....	.....	.....	W.	Cloudy
21...	44	35	9	.....	.....	.....	.....	W.	Cloudy
22...	48	33	15	.....	.....	.....	.....	W.	P. Cl.
23...	59	26	33	.....	.....	.....	.....	S.	P. Cl.
24...	56	34	22	.....	.....	.....	.....	W.	Cloudy
25...	61	40	21	.....	.....	.....	Trace	W.	Cloudy
26...	47	40	7	Night	9 A. M.	.18	Trace	W.	P. Cl.
27...	47	28	19	.....	.....	.....	.....	W.	P. Cl.
28...	47	28	19	.....	.....	.....	.....	W.	P. Cl.
29...	36	31	5	Night	6 A. M.	.19	¾ in.	W.	Cloudy
30...	36	21	15	.....	.....	.11	.....	W.	P. Cl.
31...	45	12	33	.....	.....	.....	.....	W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 54.7
Mean minimum 31.1
Mean 42.9
Maximum .....66; date, 2nd, 3rd, 5th
Minimum .....12; date, 31st
Greatest daily range 33

Precipitation.

Total ....1.11 inches
Greatest in 24 hours.... 26; date, 18th

Snow.

Total fall, .75 inches; on ground 15th, 0 inches; at end of month, 0 inches.

Number of Days.

With .01 inch or more precipitation, 7;
Clear, 10; partly cloudy, 8; cloudy, 13.

REMARKS.

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Month of April, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	56	25	31	.....	.....	.....	.....	S. W.	Clear
2...	62	26	36	.....	.....	.....	.....	E.	Clear
3...	66	30	36	.....	.....	.....	.....	W.	Clear
4...	70	25	45	.....	.....	.....	.....	W.	Clear
5...	71	35	36	.....	.....	.....	.....	S.	Clear
6...	68	36	32	.....	.....	.....	.....	N. E.	Clear
7...	60	40	20	.....	.....	.....	.....	W.	P. Cl.
8...	63	39	24	.....	.....	.....	.....	W.	P. Cl.
9...	64	33	31	.....	.....	.....	.....	W.	Clear
10...	48	28	20	Night	Night	.37	4 in.	W.	P. Cl.
11...	53	28	25	.....	.....	.....	.....	W.	P. Cl.
12...	63	29	34	.....	.....	.....	.....	W.	Clear
13...	65	36	29	.....	.....	.....	.....	W.	Clear
14...	63	27	36	.....	.....	.....	.....	W.	Clear
15...	65	39	26	.....	.....	.....	.....	W.	P. Cl.
16...	58	29	29	.....	.....	.....	.....	W.	Cloudy
17...	66	29	37	.....	.....	.....	.....	W.	P. Cl.
18...	51	40	11	.....	.....	.....	.....	W.	P. Cl.
19...	52	31	21	.....	.....	Trace	.....	W.	Cloudy
20...	58	25	33	.....	.....	.....	.....	W.	P. Cl.
21...	57	38	19	.....	.....	.....	.....	W.	Clear
22...	61	35	26	.....	.....	.02	.....	W.	P. Cl.
23...	67	31	36	.....	.....	.....	.....	E.	Clear
24...	72	35	37	.....	.....	.....	.....	W.	P. Cl.
25...	71	41	30	7:30 P. M.	Night	.89	.....	N. W.	P. Cl.
26...	66	44	22	.....	.....	.....	.....	W.	P. Cl.
27...	68	40	28	.....	.....	.....	.....	W.	P. Cl.
28...	72	38	34	.....	.....	.....	.....	W.	Clear
29...	70	48	22	.....	.....	.....	.....	W.	Clear
30...	50	37	13	.....	.....	.18	½ in.	W.	P. Cl.

MONTHLY SUMMARY.

Temperature.

Mean maximum 62.5
Mean minimum 33.9
Mean 48.2
Maximum..... 72; date, 24th, 28th
Minimum .....25; date, 1st, 4th, 20th

Precipitation.

Total ....1.46 inches
Greatest in 24 hours..... 89; date, 25th

Snow.

Total fall, 4 inches; on ground 15th, 0 inches; at end of month, 0 inches.

Number of Days.

With .01 inch or more precipitation, 4; Clear, 14; partly cloudy, 14; cloudy, 2.

REMARKS.

Month of May, 1905; Station, R eno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	60	38	22	.....	.....	.....	.....	W.	Cloudy
2...	59	32	27	.....	.....	0.36	3½ in.	N.	P. Cl.
3...	41	29	12	.....	.....	.....	.....	W.	P. Cl.
4...	54	32	22	.....	.....	.05	.....	W.	P. Cl.
5...	58	34	24	.....	.....	.....	.....	W.	P. Cl.
6...	64	32	32	.....	.....	.....	.....	W.	Clear
7...	53	43	10	.....	.....	.....	.....	W.	P. Cl.
8...	51	36	15	.....	.....	.....	Trace	W.	Cloudy
9...	43	31	12	.....	.....	0.10	.....	N. W.	Cloudy
10...	49	29	20	.....	.....	.....	.....	N. W.	Cloudy
11...	50	29	21	.....	.....	0.10	Trace	W.	Cloudy
12...	62	33	29	.....	.....	.....	.....	E.	P. Cl.
13...	65	39	26	.....	.....	.....	.....	E.	P. Cl.
14...	78	40	38	.....	.....	.....	.....	N. E.	Clear
15...	79	41	38	.....	.....	.....	.....	N. E.	Clear
16...	78	51	27	.....	.....	.....	.....	W.	Clear
17...	70	40	30	.....	.....	.....	.....	N. W.	P. Cl.
18...	66	41	25	.....	.....	.....	.....	W.	P. Cl.
19...	74	39	35	.....	.....	.....	.....	W.	P. Cl.
20...	69	41	28	.....	.....	.....	.....	W.	P. Cl.
21...	56	38	18	.....	.....	.....	.....	W.	P. Cl.
22...	67	32	35	.....	.....	.....	.....	N.	Clear
23...	69	37	32	.....	.....	.....	.....	E.	Clear
24...	75	36	39	.....	.....	.....	.....	E.	Clear
25...	72	41	31	.....	.....	.....	.....	W.	Clear
26...	52	46	6	.....	.....	.....	Trace	W.	Cloudy
27...	64	40	24	.....	.....	0.10	.....	W.	Cloudy
28...	61	46	15	.....	.....	.....	Trace	N.	Cloudy
29...	70	34	36	.....	.....	.....	.....	W.	Clear
30...	74	44	30	.....	.....	.....	.....	W.	P. Cl.
31...	74	41	33	.....	.....	.....	.....	W.	P. Cl.

MONTHLY SUMMARY.

Temperature.

Mean maximum 68.1
Mean minimum 37.6
Mean 50.3
Maximum, ...79; date, 15th
Minimum .... 29; date, 3rd, 10th, 11th
Greatest daily range .....

Precipitation.

Total ....0.71 inches
Greatest in 24 hours .....36; date, 2nd

Snow.

Total fall, 3½ inches; on ground 15th, 0 inches; at end of month, 0 inches.

Number of Days.

With .01 inch or more precipitation, 5; Clear, 9; partly cloudy, 14; cloudy, 8.

REMARKS.

Intermittent snow squalls from 8 to 11 a. m. on 9th, and during entire afternoon also.

Month of June, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	72	46	26	.....	.....	.....	.....	W.	Clear
2...	65	51	14	.....	.....	.....	.....	W.	P. Cl.
3...	66	38	28	.....	.....	.....	.....	W.	Clear
4...	61	37	24	.....	.....	.....	.....	W.	Clear
5...	66	35	31	.....	.....	.....	.....	W.	P. Cl.
6...	69	41	28	.....	.....	.....	.....	W.	P. Cl.
7...	69	39	30	.....	.....	.....	.....	W.	P. Cl.
8...	73	40	33	.....	.....	.....	.....	W.	Clear
9...	75	46	29	.....	.....	.....	.....	W.	Clear
10...	81	46	35	.....	.....	.....	.....	W.	Clear
11...	85	52	33	.....	.....	.....	.....	W.	Clear
12...	81	51	30	.....	.....	.....	.....	W.	Clear
13...	84	44	40	.....	.....	.....	.....	W.	Clear
14...	81	49	32	.....	.....	.....	.....	W.	Clear
15...	82	50	32	.....	.....	.....	.....	W.	Clear
16...	80	49	31	.....	.....	.....	.....	W.	Clear
17...	72	51	21	.....	.....	.....	.....	W.	Clear
18...	80	43	37	.....	.....	.....	.....	W.	Clear
19...	88	42	46	.....	.....	.....	.....	W.	Clear
20...	86	49	37	.....	.....	.....	.....	W.	Clear
21...	86	50	36	.....	.....	.....	.....	W.	Clear
22...	75	46	29	.....	.....	.....	.....	W.	Clear
23...	74	47	27	.....	.....	.....	.....	W.	Clear
24...	75	38	37	.....	.....	.....	.....	W.	Clear
25...	74	45	29	.....	.....	.....	.....	W.	Clear
26...	77	39	38	.....	.....	.....	.....	W.	Clear
27...	76	53	23	.....	.....	.....	.....	W.	Clear
28...	83	41	42	.....	.....	.....	.....	W.	Clear
29...	84	48	36	.....	.....	.....	.....	W.	Clear
30...	82	46	36	.....	.....	.....	.....	W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 75.7
Mean minimum 45.1
Mean 60.9
Maximum .....88; date, 19th
Minimum ....35; date, 5th
Greatest daily range.....46; date, 19th

Precipitation.

Total ....0 inches
Greatest in 24 hours .....; date, ...

Snow.

Total fall, .. inches; on ground, 15th, .. inches; at end of month, ... inches.
Number of days with .01 inch or more precipitation, 0; Clear, 26; partly cloudy, 4; cloudy, 0.

REMARKS.

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Month of July, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall.	Prevailing Wind	Character
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	81	50	31	.....	.....	.....	.....	W.	Clear
2...	85	49	36	.....	.....	.....	.....	W.	Clear
3...	91	47	44	.....	.....	.....	.....	E.	Clear
4...	92	52	40	.....	.....	.....	.....	E.	Clear
5...	95	54	41	.....	.....	.....	.....	W.	Clear
6...	94	53	41	.....	.....	.....	.....	W.	Clear
7...	96	58	38	.....	.....	.....	.....	W.	Clear
8...	96	57	39	.....	.....	.....	.....	W.	Clear
9...	98	58	40	.....	.....	.....	.....	W.	Clear
10...	96	61	35	.....	.....	.....	.....	W.	Clear
11...	93	59	34	.....	.....	.....	.....	W.	Clear
12...	86	56	30	.....	.....	.....	.....	W.	Clear
13...	82	53	29	.....	.....	.....	.....	W.	Clear
14...	83	48	35	.....	.....	.....	.....	W.	Clear
15...	78	52	26	.....	.....	.....	.....	W.	Clear
16...	81	45	36	.....	.....	.....	.....	W.	Clear
17...	86	47	39	.....	.....	.....	.....	W.	Clear
18...	88	53	35	.....	.....	.....	.....	W.	Clear
19...	91	55	36	.....	.....	.....	.....	W.	Clear
20...	93	55	38	.....	.....	.....	.....	W.	Clear
21...	96	57	39	.....	.....	.....	.....	S. W.	Clear
22...	95	60	35	.....	.....	.....	.....	W.	Clear
23...	96	60	36	3:30 P. M.	3:45	0.05	.....	W.	P. Cl.
24...	95	56	39	.....	.....	.....	.....	W.	Clear
25...	93	60	33	.....	.....	.....	.....	W.	Clear
26...	90	58	32	.....	.....	.....	.....	W.	Clear
27...	89	54	35	.....	.....	.....	.....	W.	Clear
28...	84	45	39	.....	.....	.....	.....	W.	Clear
29...	86	46	40	.....	.....	.....	.....	W.	Clear
30...	87	50	37	.....	.....	.....	.....	W:	Clear
31...	88	47	41	.....	.....	.....	.....	W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 89.8
Mean minimum 53.4
Mean 71.6
Maximum ..... 98; date, 9th
Minimum ..... 45; date, 16th, 28th
Greatest daily range 44

Precipitation.

Total ....0.05 inches
Greatest in 24 hours ....0.05; date, 23rd

Snow.

Total fall, ... inches; on ground 15th, .. inches; at end of month, .. inches.
Number of days with .01 inch or more precipitation, 1; Clear, 30; partly cloudy, 1; cloudy, 0.

REMARKS.

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Month of August, 1905; Station Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION					
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount	Snowfall, in inches	Prevailing Wind Direction	Character of Day
1...	87	49	38	.....	.....	.....	.....	W.	Clear
2...	83	51	32	.....	.....	.....	.....	W.	P. Cl.
3...	86	52	34	.....	.....	.....	.....	W.	Clear
4...	85	48	37	.....	.....	.....	.....	W.	Clear
5...	89	47	42	.....	.....	.....	.....	W.	Clear
6...	91	50	41	.....	.....	.....	.....	W.	Clear
7...	96	53	43	.....	.....	.....	.....	W.	Clear
8...	94	54	40	.....	.....	.....	.....	W.	Clear
9...	91	54	37	.....	.....	.....	.....	W.	Clear
10...	89	53	36	.....	.....	.....	.....	W.	Clear
11...	84	62	22	.....	.....	.....	.....	W.	Clear
12...	90	54	36	.....	.....	.....	.....	W.	Clear
13...	88	56	32	.....	.....	.....	.....	W.	Clear
14...	87	47	40	.....	.....	.....	.....	W.	Clear
15...	85	46	39	.....	.....	.....	.....	W.	Clear
16...	88	47	41	.....	.....	.....	.....	W.	Clear
17...	88	53	35	.....	.....	.....	.....	W.	Clear
18...	92	54	38	.....	.....	.....	.....	W.	Clear
19...	88	57	31	.....	.....	.....	.....	W.	Clear
20...	76	59	17	.....	.....	.....	.....	W.	P. Cl.
21...	93	54	39	Night	Night	0.32	.....	W.	Cloudy
22...	80	52	28	.....	.....	.....	.....	W.	Clear
23...	86	48	38	.....	.....	.....	.....	W.	Clear
24...	87	47	40	.....	.....	.....	.....	W.	Clear
25...	80	57	23	.....	.....	.....	.....	W.	Clear
26...	87	49	38	.....	.....	.....	.....	W.	P. Cl.
27...	87	50	37	.....	.....	.....	.....	W.	P. Cl.
28...	87	47	40	.....	.....	.....	.....	W.	Clear
29...	88	46	42	.....	.....	.....	.....	W.	Clear
30...	85	50	35	.....	.....	.....	.....	W.	Clear
31...	87	48	39	.....	.....	.....	.....	W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 87.2
Mean minimum 51.4
Mean 69.3
Maximum, ...96; date, 7th
Minimum ..... 46; date, 15th, 29th
Greatest daily range 42

Precipitation.

Total ....0.32 inches
Greatest in 24 hours, 0.32; date, 21st.

Snow.

Total fall, ... inches; on ground 15th, .. inches; at end of month, ..inches.

Number of Days.

With .01 inch or more precipitation, 1; Clear, 26; partly cloudy, 4; cloudy, 1.

REMARKS.

Air full of smoke from forest fires on the 28th, 29th, 30th, 31st.

Month of September, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	90	50	40	.....	.....	.....	.....	W.	Clear
2...	88	49	39	.....	.....	.....	.....	W.	Clear
3...	84	45	39	.....	.....	.....	.....	W.	Clear
4...	81	48	33	.....	.....	.....	.....	W.	Clear
5...	81	46	35	.....	.....	.....	.....	W.	P. Cl.
6...	83	48	35	.....	.....	.....	.....	W.	P. Cl.
7...	84	48	36	.....	.....	.....	.....	W.	P. Cl.
8...	84	48	36	.....	.....	.....	.....	W.	P. Cl.
9...	82	48	34	.....	.....	.....	.....	W.	P. Cl.
10...	77	52	25	.....	.....	Trace	.....	W.	Clear
11...	78	45	33	.....	.....	.....	.....	W.	Clear
12...	74	44	30	.....	.....	.....	.....	W.	Clear
13...	74	38	36	.....	.....	.....	.....	W.	Clear
14...	82	40	42	.....	.....	.....	.....	W.	Clear
15...	84	44	40	.....	.....	.....	.....	W.	Clear
16...	78	40	38	.....	.....	.....	.....	W.	Clear
17...	70	53	17	.....	.....	.....	.....	W.	Clear
18...	70	43	27	.....	.....	.....	.....	W.	Clear
19...	81	39	42	.....	.....	.....	.....	W.	Clear
20...	84	43	41	.....	.....	.....	.....	W.	Clear
21...	87	44	43	.....	.....	.....	.....	W.	Clear
22...	86	45	41	.....	.....	.....	.....	W.	Clear
23...	80	48	32	Night	Night	Trace	.....	W.	P. Cl.
24...	74	48	26	.....	.....	.....	.....	W.	P. Cl.
25...	75	40	35	.....	.....	.....	.....	W.	Clear
26...	83	45	38	.....	.....	.....	.....	W.	Clear
27...	70	56	14	6 P. M.	Night	0.10	.....	W.	Clear
28...	53	40	13	.....	.....	.....	.....	W.	P. Cl.
29...	58	31	27	.....	.....	.....	.....	W.	Clear
30...	70	33	37	.....	.....	.....	.....	W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 78.2
Mean minimum 47.7
Mean 61.4
Maximum ....90; date, 1st
Minimum, ... 31; date, 29th
Greatest daily range 43

Precipitation.

Total ....0.10 inches
Greatest in 24 hours, 0.10; date, 27th

Snow.

Total fall, ..inches; on ground 15th, .. inches; at end of month, .. inches.

Number of Days.

With .01 inch or more precipitation, 1; Clear, 20; partly cloudy, 8; cloudy, 2.

REMARKS.

White frost 5:30 a. m. on 16th. On 24th potato and tomato plants were brown and dead from frost on ranches west of Reno. Alfalfa unharmed.

Month of October, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION				Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount	Snowfall, in inches		
1...	72	36	36					W.	Clear
2...	79	38	41					W.	Clear
3...	81	43	38					W.	Clear
4...	80	39	41					W.	Clear
5...	75	51	24					W.	Clear
6...	74	53	21					W.	Clear
8...	52	28	24					W.	P. Cl.
9...	60	32	28					W.	Clear
7...	64	46	18		Trace			W.	Clear
10...	63	30	33					W.	Clear
11...	71	30	41					W.	Clear
12...	73	33	40					W.	Clear
13...	55	37	18					W.	Clear
14...	67	28	39					W.	Clear
15...	61	28	33					W.	Clear
16...	50	24	26					W.	Clear
17...	55	21	34					W.	Clear
18...	51	31	20					W.	Clear
19...	57	23	34					W.	Clear
20...	59	24	35					W.	Clear
21...	63	25	38					W.	Clear
22...	59	27	32					W.	Clear
23...	65	25	40					W.	Clear
24...	70	31	39					W.	Clear
25...	72	26	46					W.	Clear
26...	71	34	37					W.	Clear
27...	67	34	33					W.	Clear
28...	69	33	36					W.	Clear
29...	68	29	39					W.	Clear
30...	58	31	27					W.	Clear
31...	50	34	16					W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 64.8
Mean minimum 32.4
Mean 48.6
Maximum ....81; date, 3rd
Minimum ..... 21; date, 17th
Greatest daily range 46

Precipitation.

Total ....Trace
Greatest in 24 hours, trace; date, 7th

Snow.

Total fall, .. inches; on ground 15th, .. inches; at end of month, .. inches

Number of Days.

With .01 inch or more precipitation, 0; Clear, 39; partly cloudy, 1; cloudy, 0.

REMARKS.

Month of November, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION				Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount	Snowfall, in inches		
1...	60	26	34	.....	.....	.....	.....	W.	Clear
2...	67	26	41	.....	.....	.....	.....	W.	Clear
3...	56	29	27	.....	.....	.....	.....	N.	Clear
4...	48	26	22	.....	.....	.....	.....	N. E.	Clear
5...	47	25	22	.....	.....	.....	.....	N.	P. Cl.
6...	54	26	28	.....	.....	.....	.....	N. E.	Clear
7...	60	23	37	.....	.....	.....	.....	N. E.	Clear
8...	60	24	36	.....	.....	.....	.....	E.	Clear
9...	61	23	38	.....	.....	.....	.....	E.	Clear
10...	64	23	41	.....	.....	.....	.....		Clear
11...	61	24	37	.....	.....	.....	.....		Clear
12...	63	23	40	.....	.....	.....	.....		Clear
13...	61	21	40	.....	.....	.....	.....		Clear
14...	62	21	41	.....	.....	.....	.....		Clear
15...	64	22	42	.....	.....	.....	.....		Clear
16...	55	33	22	.....	.....	.....	.....		Cloudy
17...	61	36	25	.....	.....	.....	.....		P. Cl.
18...	58	30	28	.....	.....	.....	.....		P. Cl.
19...	57	26	31	.....	.....	.01	.....		P. Cl.
20...	32	27	5	.....	.....	.05	.....		Cloudy
21...	34	24	10	.....	.....	.11	.....		Cloudy
22...	41	25	16	.....	.....	.....	.....		P. Cl.
23...	42	28	14	.....	.....	.....	.....		P. Cl.
24...	46	23	23	.....	.....	.....	.....		Clear
25...	48	18	30	.....	.....	.....	.....		Clear
26...	48	21	27	.....	.....	.....	.....		P. Cl.
27...	34	23	11	.....	.....	.05	.....		P. Cl.
28...	36	16	20	.....	.....	.17	.....		Clear
29...	38	25	13	.....	.....	.05	.....		Cloudy
30...	38	22	16	.....	.....	.01	.....		P. Cl.

MONTHLY SUMMARY.

Temperature.

Mean maximum 51.9
Mean minimum 24.6
Mean 38.2
Maximum ..... 67; date, 2nd
Minimum ....16; date, 28th
Greatest daily range 42

Precipitation.

Total ....0.45 inches
Greatest in 24 hours ....17; date, 28th

Snow.

Total fall, .. inches; on ground 15th, .. inches; at end of month, .. inches.

Number of Days.

With .01 inch or more precipitation, 7; Clear, 30; partly cloudy, 1; cloudy, 0.

REMARKS.

We are indebted to H. F. Alps of the U. S. Weather Bureau for the daily observations after the 9th.

Month of December, 1905; Station, Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION			Snowfall, in inches	Prevailing Wind Direction	Character of Day
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount			
1...	38	12	26	.....	.....	.....	.....		Clear
2...	42	15	27	.....	.....	.....	.....		Clear
3...	42	17	25	.....	.....	.....	.....		Clear
4...	42	14	28	.....	.....	.....	.....		Clear
5...	40	18	22	.....	.....	.....	.....		Clear
6...	45	15	30	.....	.....	.....	.....		Clear
7...	48	18	30	.....	.....	.....	.....		Clear
8...	34	15	19	.....	.....	.....	.....		Clear
9...	40	11	29	.....	.....	.....	.....		Clear
10...	40	8	32	.....	.....	.....	.....		Clear
11...	41	9	32	.....	.....	.....	.....		Clear
12...	41	9	32	.....	.....	.....	.....		P. Cl.
13...	42	18	24	.....	.....	.....	.....		Cloudy
14...	45	20	25	.....	.....	.....	.....		Cloudy
15...	49	20	29	.....	.....	.....	.....		P. Cl.
16...	51	24	27	.....	.....	.....	.....		Clear
17...	41	19	22	.....	.....	.....	.....		Cloudy
18...	46	29	17	.....	.....	.....	.....		P. Cl.
19...	45	34	11	.....	.....	Trace	.....		Cloudy
20...	36	18	18	.....	.....	Trace	.....		P. Cl.
21...	35	10	25	.....	.....	.....	.....		Clear
22...	31	9	22	.....	.....	.....	.....		Clear
23...	35	8	27	.....	.....	.....	.....		P. Cl.
24...	42	7	35	.....	.....	.....	.....		P. Cl.
25...	50	16	34	.....	.....	.....	.....		Cloudy
26...	51	35	16	.....	.....	Trace	.....		P. Cl.
27...	41	24	17	.....	.....	.....	.....		P. Cl.
28...	42	17	25	.....	.....	.03	.....		P. Cl.
29...	28	10	18	.....	.....	.....	.....		Clear
30...	44	14	30	.....	.....	.05	.....		P. Cl.
31...	28	14	14	.....	.....	.....	.....		P. Cl.

MONTHLY SUMMARY.

Temperature.

Mean maximum 41.1
Mean minimum 16.4
Mean 28.7
Maximum ..... 51; date, 26th
Minimum ....7; date, 24th
Greatest daily range 35

Precipitation.

Total ....0.08 inches
Greatest in 24 hours ...0.05; date, 30th

Snow.

Total fall 1.2 inches; on ground 15th, .. inches; at end of month, 0.3 inches.

Number of Days.

With .01 inch or more precipitation, ..; Clear, 15; partly cloudy 11; cloudy, 5.

REMARKS.

This record was transcribed from the monthly summary of the U. S. Weather Bureau through the courtesy of Mr. H. F. Alps.

Nevada U of

AGRICULTURAL EXPERIMENT STATION
THE UNIVERSITY OF NEVADA

Bulletin No. 94 June, 1918

ONE-NIGHT CAMPS
VS.
ESTABLISHED BED-GROUNDS
On Nevada Sheep Ranges

By

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ONE-NIGHT CAMPS vs. ESTABLISHED BED-GROUNDS

INTRODUCTION

This bulletin reports the results of experiments during two seasons to determine (1) whether it is practical to handle sheep on summer ranges in Nevada without returning each night to an established camp; and (2) the effect of such a system of handling on the sheep and the range in comparison with the prevailing method of returning each night to a fixed bed-ground.

In Nevada the general method of handling sheep on the summer grazing ranges of the public domain is to make a permanent bed-ground to which the sheep are returned each night until all the forage within a radius of a mile to three miles of the bed-ground is consumed, when a new camp is established. Quite frequently, under this system of handling, the sheep are close-herded; dogs are employed more often than is good either for the sheep or the range; unnecessary trailing, running, and massing take place; the range forage is cut up and destroyed by the hoofs, and there is a material loss of flesh in both ewes and lambs.

In order than this loss of flesh and destruction of range might be reduced, a study was made during the summers of 1916 and 1917 to determine under Nevada conditions what the advantage to the ewe and her lamb would be and what difference it would make in the carrying capacity of the range if the sheep were allowed at all times to graze contentedly, openly, and quietly, and were allowed to bed down wherever they were overtaken by night instead of being driven back each night to a permanent bed-ground.

Three flocks were studied under each system during the summers of 1916 and 1917. The details, results, and conclusions for the two systems follow:

THE KIND OF RANGE WHICH WAS STUDIED

In order to compare results from the two systems we had to find a good big piece of range which was very much the same all over, and make our trials there. The grasses and plants had to be the same; they had to be about as thick on one part of the trial range as on the other. The country had to be about the same on one part as the other, with the same amount of water on both. The range selected was an open grass-land region, a rolling hill country where the sheep could get at all of it easily. The grass was about the same on all of it, and the kind of country and watering-places were very much alike. It was an ideal range on which to try out the two systems of camping.

The forage was made up mainly of grasses, with a scattering growth of weeds and browse. There was very little timber, only a few scattered patches of aspen, which were used by the sheep to good advantage for shade during the heat of the day. On the average about seven-tenths of the surface of the ground was occupied by plant growth consisting of possibly 75% grass and 20% weeds and 5% browse. About 7% of the forage was not utilized. Because it was an exceedingly uniform range, any differences in carrying

Figure 1. Sheep grazing openly, quietly, and contentedly. Heavier lambs, fewer cripples, and fat ewes will result at the end of the summer grazing season.

capacity can only be attributed to the methods used in handling the sheep.

BREEDS OF SHEEP USED

The ewes handled under the various tests were mainly fine-wools, with a good many showing the long-wool characteristic of the Lincolns and Cotswolds, or the typical black and brown faces of the Shropshire and Hampshire. However, the foundation blood consisted mainly of Merino and Rambouillet.

HERDING QUALITIES OF THE VARIOUS BREEDS STUDIED

From all observations made during the two seasons, it appears that the fine-wool sheep taken collectively are more easily herded and handled than either the mutton or the coarse-wool breeds.

The western sheepman has never developed a type of sheep which would meet his own special needs. He has taken the various breeds which have originated from the peculiar standards of the various breeders, from environment, and from the varying character of climate, forage and soil, and adapted them as best he could to meet his own varied economic conditions. Because of this intermingling of breeds there are few flocks of pure-bred sheep on our western ranges. Consequently the wool is far from being uniform, the herding qualities vary in different flocks, the lambs produced are decidedly uneven, and the ability to withstand severe winters varies according to the breed of the sheep being handled. However, sheep especially adapted to western range conditions must have the ability to stand severe storms, with little or no protection, and to maintain themselves during periods of drought and starvation; they must be good shearers, and must have an inbred tendency to herd well without unnecessary trailing and straying.

The fine-wool sheep, therefore, have a big advantage on our western ranges over most other breeds because the environment under which they were developed and produced gave them a pronounced ability to sustain themselves on scanty coarse feed.

As rustlers they are entitled to first place. On account of this active rustling habit, they are more particularly adapted than other breeds for grazing on our rough broken ranges where they are forced to cover a large area in order to get their feed. Further, sheep on our Nevada ranges are kept to average age of seven to eight years, and the fine-wool breeds will hold their wool better than any other breed to this age. The mutton breeds soon become light shearers, the wool getting especially thin over the stomachs. Of all the breeds observed, the fine-wools utilized the range forage most efficiently; and their lambs, produced by crossing blocky mutton-bred sires, were the most promising on the range.

HERDERS

The herders in every instance were Basques. In Nevada practically all of the sheep are handled by this class of herders. As a general rule, after being given the proper instructions they are very reliable and conscientious shepherds. The herders who handled the sheep under observation all had more or less ability and displayed considerable energy, but they did not handle their flocks in the same manner. This difference in the methods of handling, offered an

Figure 2. Running the wool and mutton off the sheep. The lazy herder's way of herding. His lambs would weigh at the end of the season from 5 to 7 pounds more if all the unnecessary dogging and running were cut out.

excellent opportunity for working out comparative range-carrying capacity tests, and average daily gains made by lambs under the existing methods of handling sheep on our public domain range. The greatest difference in the methods of the various herders was that a few changed their bed-ground daily and allowed their sheep at all times to graze openly and quietly, while others close-herded their sheep and returned them each night to an established camp until all the feed within a radius of two to three miles was grazed off. Then the camp would be moved by the camp-tender and a new bed-ground made on some other part of the range. A comparison of the two systems follows.

ESTABLISHED BED-GROUND SYSTEM

When the animals are handled under this system a main camp is established to which the sheep are returned each night and bedded down. On this bed-ground with the herder they remain all night without any attention until early morning, when they commence to become restless, because their stomachs are empty and they are anxious to begin feeding. The herder must now be on duty to direct them toward the area where he wishes them to graze during the day.

BEDDING-OUT SYSTEM

Under the system just explained the sheep are returned to a permanent bed-ground each night, but with the bedding-out system they are allowed to bed down on a new area each night. This means a new bed-ground every day or a new bed-ground every third day in case of wet or stormy weather, when it would be impracticable to move camp. However, under Nevada conditions, there are but few nights during the summer when it is wet and cold, so that, practically speaking, it is entirely feasible to have a new bed-ground every night.

Under this system, rather than to graze the vicinity of a camp to full capacity and injure or ruin the range forage as under the old system, it is left in good condition and grazed again at a later date. The sheep are always on fresh feed, which allows them to graze during the cool morning and evening hours and to seek shade during the hot part of the day.

As soon as the sheep leave the bed-ground in the morning they immediately begin to spread out; some going in one direction and some in another. Some travel fast and others slow. In a short time if they are not checked they will have spread over a large area, and instead of being in a compact bunch, as they were when they left the bed-ground, they will have commenced to separate into smaller bunches.

At this stage, or even before, the lazy herder, or the one who uses the "close-bunched" herding system of handling, resorts to the use of the dogs and soon has the sheep rounded up into a more or less compact bunch. Dogging, running, and trailing go on all day until the sheep are returned at night to the bed-ground.

Some indifferent herders continually use their dogs in order to keep the tail end of the herd up with the leaders; but the energetic conscientious herder will keep himself moving around the outside of the flock constantly turning or retarding the leaders. This allows

Figure 3. Sheep ready to bed down at evening on a new bed-ground. If the bed-ground is changed daily, the lambs will grow more rapidly, and the range will not be abused.

all the animals to graze contentedly with the greatest possible chance to exercise choice in the selection of forage. The sheep are allowed to bed down wherever they may be when night overtakes them.

If the heaviest range lambs are to be produced from a given piece of range, the system outlined above must be used. The ideal way of handling sheep on the range should approach as nearly as possible the manner of grazing within a pasture where the animals do the least amount of trailing from one place to another and where they are at all times allowed to graze openly and quietly without being disturbed. Of course, it is impossible under our present public domain conditions to handle sheep on the range under fence; but the pasturage system should be the ideal and should be approached as closely as possible. This means that tail-end herding must be done away with and the herding take place from the sides and front, the herder continually turning at all times the fast-trailing leaders. The slow-grazing sheep which are feeding in the rear of the flock will not then have to keep up with the fast-trailing leaders. This gives all the animals in the flock an equal chance to fill in the shortest possible time.

This is by no means a lazy man's way of herding, but it means an increase in the carrying capacity of the range, and means the production of heavier range lambs, fatter ewes, and fewer cripples. It simply means grazing with the least possible herding or actual driving. It allows the sheep to graze continually in the cool morning hours and to "buck up" during the heat of the day. It permits them to graze with quiet natural freedom, which favors the most efficient production of wool and mutton.

EQUIPMENT NECESSARY UNDER EACH SYSTEM

Under the old system of returning to an established camp each night the herder is usually supplied with two tents. One he uses for cooking and for storing supplies; the other he sleeps in. Frequently, however, the cook tent is very close to the bed-ground, so that he may use it if he wishes for cooking, storage, and sleeping. Generally he is not supplied with any means of transportation, depending entirely upon the camp-tender to do all of the moving of his camp supplies.

When the bedding-out system of one-night camps is used, the herder must have a horse or a burro on which he can lash his tent, bed, and provisions every day for transportation to the newly established bed-ground. A burro will carry the average summer-weight bed all day and never feel any discomfort; and, further, he will graze as one of the sheep. He is a very hardy inexpensive animal and will graze almost any area where sheep will feed. On some ranges the herders carry their beds on their backs to the new bed-ground. However, on most ranges it will pay a lot better to use a burro.

The most practical tent for the herder is a tepee. In heavy storms it gives the best protection, and when transported it is very easily taken down and set up. It is light in weight and not at all bulky. Possibly the most convenient way of carrying bed and tent is simply to take down the tepee in the morning, lash it on the burro, turn him

Figure 4. All day the burro carries the bed and tepee, grazing as one of the flock. At night the burro, the sheep, and the herder bed down wherever they are on the range. Open grazing and one-night camps mean increased profits to the owner, more mutton and wool for the Nation, and little abuse to the range plants.

Month of August, 1905; Station Reno; County, Washoe; State, Nevada.

Date	TEMPERATURE			PRECIPITATION					
	Maximum.	Minimum.	R'nge	Time of Beginning	Time of Ending	Amount	Snowfall, in inches	Prevailing Wind Direction	Character of Day
1...	87	49	38	.....	.....	.....	.....	W.	Clear
2...	83	51	32	.....	.....	.....	.....	W.	P. Cl.
3...	86	52	34	.....	.....	.....	.....	W.	Clear
4...	85	48	37	.....	.....	.....	.....	W.	Clear
5...	89	47	42	.....	.....	.....	.....	W.	Clear
6...	91	50	41	.....	.....	.....	.....	W.	Clear
7...	96	53	43	.....	.....	.....	.....	W.	Clear
8...	94	54	40	.....	.....	.....	.....	W.	Clear
9...	91	54	37	.....	.....	.....	.....	W.	Clear
10...	89	53	36	.....	.....	.....	.....	W.	Clear
11...	84	62	22	.....	.....	.....	.....	W.	Clear
12...	90	54	36	.....	.....	.....	.....	W.	Clear
13...	88	56	32	.....	.....	.....	.....	W.	Clear
14...	87	47	40	.....	.....	.....	.....	W.	Clear
15...	85	46	39	.....	.....	.....	.....	W.	Clear
16...	88	47	41	.....	.....	.....	.....	W.	Clear
17...	88	53	35	.....	.....	.....	.....	W.	Clear
18...	92	54	38	.....	.....	.....	.....	W.	Clear
19...	88	57	31	.....	.....	.....	.....	W.	Clear
20...	76	59	17	.....	.....	.....	.....	W.	P. Cl.
21...	93	54	39	Night	Night	0.32	.....	W.	Cloudy
22...	80	52	28	.....	.....	.....	.....	W.	Clear
23...	86	48	38	.....	.....	.....	.....	W.	Clear
24...	87	47	40	.....	.....	.....	.....	W.	Clear
25...	80	57	23	.....	.....	.....	.....	W.	Clear
26...	87	49	38	.....	.....	.....	.....	W.	P. Cl.
27...	87	50	37	.....	.....	.....	.....	W.	P. Cl.
28...	87	47	40	.....	.....	.....	.....	W.	Clear
29...	88	46	42	.....	.....	.....	.....	W.	Clear
30...	85	50	35	.....	.....	.....	.....	W.	Clear
31...	87	48	39	.....	.....	.....	.....	W.	Clear

MONTHLY SUMMARY.

Temperature.

Mean maximum 87.2
Mean minimum 51.4
Mean 69.3
Maximum, ...96; date, 7th
Minimum ..... 46; date, 15th, 29th
Greatest daily range 42

Precipitation.

Total ....0.32 inches
Greatest in 24 hours, 0.32; date, 21st.

Snow.

Total fall, ... inches; on ground 15th, .. inches; at end of month, ..inches.

Number of Days.

With .01 inch or more precipitation, 1; Clear, 26; partly cloudy, 4; cloudy, 1.

REMARKS.

Air full of smoke from forest fires on the 28th, 29th, 30th, 31st.

moved. It took him much longer to get the sheep on fresh feed in the morning than to return them to the bed-ground at night due to the fact that the sheep would graze on areas over which they had been before and consequently traveled much more slowly. However, as soon as they commenced to fill they trailed much faster and would soon reach fresh feed. The above figures approximate the average time consumed in the daily trailing to and from an established camp for a number of nights in succession. The long trail each morning and night works the greatest hardship on the sheep because they are allowed to graze but little, at a time when they are most anxious to feed; and in the evening the herder is usually very anxious to get back to camp and cook his supper, and consequently trails them in just as rapidly as possible by whistling, shouting, and the use of his dogs.

For range sheep, more especially lambs, to make the best gains, they should be allowed to graze during the cool evening and morning hours. This is not done when they are forced to trail over range which has already been grazed, as is always the case when the established bed-ground system is used. If they are not forced to make the long daily trail to and from an established camp, the general result will be a material increase in the carrying capacity of the range and a marked increase in the growth of the lambs.

SALTING

Too much emphasis cannot be placed upon the importance of giving the sheep a regular and liberal amount of salt. When the sheep are returned each night to an established camp it is comparatively easy to put sufficient salt at one time on the bed-ground to last them for five or more days. However, even under this system some herders do not salt their sheep more often than once a week, which is entirely too seldom. The best results are obtained when the sheep are given a little salt each day. When the camp is being moved daily this is more or less impracticable. Notwithstanding, they should be salted every three days. This will, in most instances, keep their appetites normal. As soon as sheep become salt-hungry they become restless and will eat many plants that normally they will not touch. A perverted taste is developed, and, of course, with this abnormal taste many cases of poisoning take place which could be avoided had the sheep been regularly salted. The best salt to use is the fine table salt, next to this the crystalline dairy salt. The rock salt is very unsatisfactory, for the reason that it takes a sheep a long time to get an amount sufficient to satisfy its wants. Further, this salt is very hard on the teeth of the sheep.

There are several ways of distributing salt to sheep on the range. One of the most common is to scatter the salt in several small piles, fifty to a hundred in number, on the bed-ground, the number of piles depending on the size of the flock. This will give all the sheep a chance to get at the salt without unnecessary crowding and will allow each sheep to get the proper amount. A much less common way is to have five or six galvanized tubs which will nest in each other (Figure 6). These tubs waste no salt, and are light and easily

transported. An excellent way of salting on the range to reduce the loss of salt is by the use of canvas troughs as shown in Figure 7. These are made by sewing 12- or 14-oz. canvas together to form a trough approximately twelve feet long, at the end of which are attached wooden end-plates. These troughs are then stretched and anchored to the ground by means of stakes as shown in the illustration, or by means of a steel stake which is attached to the end-pieces and driven into the ground, making stationary the lower part of the trough, while the upper part is made solid by means of small guide ropes. A considerable amount of salt taken to the sheep camps is wasted on the salt grounds. After salt has been transported long distances by wagon and pack-horse it becomes quite expensive. The loss may be in part or entirely avoided by the use of simple devices such as those described.

Figure 6. These small tubs nest each in another. They save salt and are easy to carry.

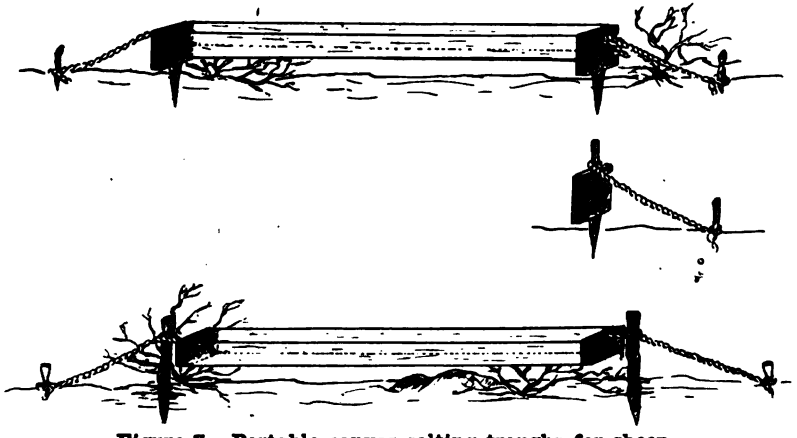

Figure 7. Portable canvas salting troughs for sheep.

When sheep are given salt at long irregular intervals it upsets, in a very pronounced manner, the digestive functions, causing scouring. The best results observed among several flocks were when the sheep were given one-half ounce daily—that is, three pounds to every hundred sheep. The sheep actually consumed this amount daily, and these figures do not take into account any waste. If the animals are salted in such a way that part of the salt is lost, then a larger quantity of salt per head must be supplied. The above figures are very easy to remember when estimating the actual amount of salt which must be consumed daily per head on the range in order to keep the appetites normal and to make the largest daily gain in flesh from the range forage consumed. This is the smallest amount that they should receive when grazing on the open range.

COMPARATIVE CARRYING CAPACITY OF RANGE UNDER BOTH SYSTEMS

Not only does the carrying capacity of the range vary according to the different kinds of plants making up the forage grazing types and the density of forage growing on them, but it also varies according to the manner in which the sheep are handled. In order to determine the difference in the carrying capacity of the range when the sheep were handled under the old system of returning to a permanent bed-ground and when they were allowed to bed down wherever night overtook them, six sheep ranges were selected for comparative study during the summers of 1916 and 1917.

The following table gives the carrying capacity of the range for each of the areas under observation:

Sheep Handled Under Bedding-Out System

Flock	Year	Ewes	Lambs*	Total sheep	Actual days of grazing	Total acreage grazed	Acreage utilized per day per sheep	Acreage utilized per 100 days per sheep
No. 1	1916	1,656	1,492	2,402	73	3,413	.0195	1.95
No. 2	1916	1,881	1,515	2,638	63	2,938	.0177	1.77
No. 3	1916	1,485	1,273	2,121	62	2,669	.0203	2.03
No. 4	1917	1,573	988	2,067	60	2,410	.0194	1.94
No. 5	1917	1,883	1,007	2,386	49	1,776	.0152	1.52
No. 6	1917	2,011	1,172	2,597	62	2,775	.0172	1.72
Average							.0182	1.82

*Two lambs considered equivalent to one mature sheep

Sheep Handled Under Established Bed-Ground System

Flock	Year	Ewes	Lambs*	Total sheep	Actual days of grazing	Total acreage grazed	Acreage utilized per day per sheep	Acreage utilized per 100 days per sheep
No. 1	1916	1,439	1,421	2,149	55	2,697	.0227	2.27
No. 2	1916	1,604	1,583	2,395	67	3,915	.0244	2.44
No. 3	1916	1,685	1,602	2,486	66	3,413	.0208	2.08
No. 4	1917	1,825	1,100	2,375	62	3,050	.0207	2.07
No. 5	1917	1,930	1,080	2,470	65	4,050	.0252	2.52
No. 6	1917	2,012	820	2,422	88	5,578	.0261	2.61
Average							.0233	2.33

*Two lambs considered equivalent to one mature ewe.

From the above tables the ewes and lambs handled under the bedding-out system utilized 1.82 acres per sheep per 100 days grazing season as compared to 2.33 acres per sheep per 100 days when they were returned to an established camp each night, a difference of 21.4% in favor of the bedding-out system in acres actually required to support a sheep for any given length of time.

This increase in carrying capacity when the two statements are compared may be accounted for by the facts that (1) the sheep are not forced to return each night over range already fully utilized, but are allowed to pass over an area only once and thus the loss of forage through trampling is reduced to a minimum; (2) a given area

of range is not fully utilized at one time, but is regrazed at a later date, thus permitting the plants to put forth fresh leaves after once being cropped, instead of being completely eaten to the ground, which materially impairs the vitality of the plants for any future growth during that season; (3) when allowed to graze openly and quietly they are spread out in open formation and only a few hoofs, at most, will strike any given plant, which minimizes injury to the plant from hoofing; (4) less waste of forage takes place, for sheep trail less when choice feed is available; (5) there is less packing of the soil; packing causing it to dry out more rapidly with the consequent retarding in the growth of the range plants, and (6) a more uniform utilization of the area grazed takes place as it eliminates overgrazing and extremely close grazing in the immediate vicinity of the established bed-ground and incomplete utilization of more distant areas.

If a certain area of sheep range has a carrying capacity of 5,000 head under the established bed-ground system, then with a saving of 21.4% of vegetation which actually takes place where the bedding-out system is used, that same range, under the latter system, would have a carrying capacity not of 5,000 head but of 6,070. If such a conservation of forage could be effected over all of our public domain range, it would mean a tremendous increase in the carrying capacity of our summer grazing ranges, or, in other words, a much larger number of stock could be ranged than at the present time. Even if no more animals were run than at the present time, the present depleted public domain ranges would have a chance to revegetate by native seeding.

GRAZING UTILIZATION UNDER EACH SYSTEM

In order to determine the degree of utilization of the range when the sheep were returned to a fixed bed-ground as compared with the system of being allowed to bed where night overtook them, a series of small areas or quadrates six feet square were selected on two different ranges before the sheep began to graze them and the total number of plants on each of the small areas listed. At the close of the grazing season the plants were again recorded in order to determine the number removed or the degree of utilization of forage which had taken place for each range. The two areas selected for this test were open rolling country where it was possible for the sheep to utilize every portion of the range with ease. The main type of forage growing on these ranges was grasses and weeds having a very uniform density over all of the area grazed.

The quadrates on the range where the sheep were returned to a fixed bed-ground were laid out from a central camp so that a quadrate was found in the ¼-mile, ½-mile, ¾-mile, 1-mile, 1¼-mile, 1¾-mile, and 2-mile zones, respectively. At the close of the season 97% of the plants had been removed in the ¼-mile zone, 95% in the ½-mile zone, 93% in the ¾-mile zone, 68% in the 1-mile zone, 48.4% in the 1¼-mile zone, 20.5% in the 1½-mile zone, 14.1% in the 1¾-mile zone,

Figure 8. Ideal system of herding on the range. Some are standing, some lying down, others quietly grazing. This means that more sheep can be grazed on a given area and more wool and mutton produced.

and in the 2-mile zone no appreciable utilization had taken place. Thus, there was overgrazing in the immediate vicinity of the bed-ground and no use made of the range two miles away.

On the range where the sheep had been allowed to select their bed-ground each night, out of the 32 quadrates established an average of 84.4% of the plants had been removed from each quadrate, and thus a very uniform utilization of the entire area had taken place, only 15.6% as an average of the forage being left ungrazed. On this range no area was completely grazed at one time, but was left to be regrazed at a later date. As a result, no injury was done to any part of this range, while in the case of the range where the sheep were returned to a central camp the range was badly abused and overgrazed in the vicinity of the bed-ground. Of course, the percentages given will vary with each different range and even with the same range, depending on the herder and the length of time the sheep are on the range, the climatic conditions affecting the growth of the forage plants, and the size of the flock. However, they do give comparative figures which illustrate admirably the fact that the range forage may be efficiently utilized or badly abused simply by the manner in which the sheep are handled.

There can be no question that the carrying capacity of the range, where equal and uniform grazing takes place, is materially greater than where certain portions are injured by overgrazing and other portions scarcely two miles from the central camp are not used at all.

Where the sheep graze on a different area each day, the plants are allowed to go to seed. Ordinarily this would not take place if all the forage had been removed at one time as it is around a fixed bed-ground. Thus, not only is there a material saving in forage, due to the elimination of waste through trailing and overgrazing, but the carrying capacity of the range may even increase each year because the plants already found on the range are allowed to go to seed.

COMPARATIVE GAINS MADE BY LAMBS UNDER EACH SYSTEM

In order to determine the effect of each system upon the growth of lambs, twenty average individuals were chosen from each flock, weighed at the beginning of the grazing season and again at the close. The comparative gains made by the various groups of lambs are given in the following tables:

Gains Made by Lambs Under Bedding-Out System

Flock	Year	Actual days of grazing	Average weight at—		Gain per head	Average gain per day
			Beginning	Close		
No. 1	1916	73	42.3 lbs.	70.0 lbs.	27.7 lbs.	.380 lbs.
No. 2	1916	63	45.5 lbs.	69.1 lbs.	23.6 lbs.	.375 lbs.
No. 3	1916	62	43.8 lbs.	66.0 lbs.	22.2 lbs.	.359 lbs.
No. 4	1917	42	45.2 lbs.	61.5 lbs.	16.3 lbs.	.390 lbs.
No. 5	1917	49	47.4 lbs.	64.3 lbs.	16.9 lbs.	.345 lbs.
No. 6	1917	62	47.0 lbs.	68.7 lbs.	21.7 lbs.	.350 lbs.
Average		58.5	45.2 lbs.	66.6 lbs.	21.4 lbs.	.3665 lbs.

Gains Made by Lambs Under Established Bed-Ground System

Flock	Year	Actual days of grazing	Average weight at—		Gain per head	Average gain per day
			Beginning	Close		
No. 1	1916	55	52.0 lbs.	67.0 lbs.	15.0 lbs.	.273 lbs.
No. 2	1916	67	33.6 lbs.	53.8 lbs.	20.2 lbs.	.302 lbs.
No. 3	1916	66	38.1 lbs.	60.4 lbs.	22.3 lbs.	.338 lbs.
No. 4	1917	62	36.2 lbs.	57.2 lbs.	21.0 lbs.	.340 lbs.
No. 5	1917	65	30.4 lbs.	51.7 lbs.	21.3 lbs.	.328 lbs.
No. 6	1917	68	35.1 lbs.	56.5 lbs.	21.4 lbs.	.315 lbs.
Average		63.8	37.5 lbs.	57.7 lbs.	20.2 lbs.	.316 lbs.

From the above tables the lambs grazed under the bedding-out system made an average gain of .3665 of a pound per day as compared to an average gain of .316 of a pound when handled under the system of returning to an established bed-ground, or a difference of .0505 pounds per head per day in favor of the lambs grazed under the bedding-out system. This appears to be a rather unimportant difference; yet when it is applied to the growth of a lamb for a grazing season of 100 days it represents an increase in the weight of the lamb by 5.05 pounds, as compared to a lamb that is herded under the system of being brought back to an established camp each night. For a flock of 1,500 lambs it means a net increase of 7,575 pounds.

On January 1, 1917, the statistics show that there were 1,340,000 sheep within the State of Nevada. Assuming that 20% of this number are yearlings, bucks, and immature animals, it leaves 1,072,000 mature breeding ewes. The 1,072,000 breeding ewes should under ordinary range conditions produce a crop of 80% docked lambs or 857,600 lambs to go onto the summer grazing ranges. It is highly improbable, but say that one-half of these lambs are now being run under the best methods of handling, so as to produce the maximum growth in the lamb during the average summer grazing period. Now, if by improved methods of handling the weight of each lamb can be increased for the other one-half by 5.05 pounds, as shown by the figures of the preceding tables, the total increased production for the State, over what it is now would be 2,165,440 pounds of mutton for the same amount of range forage utilized. If the increased production per lamb only amounted to 2 pounds, the total increase would be extremely important.

The increased money value at 14 cents per pound for a flock of 1,500 lambs would amount to 1,500 times 5.05 pounds times .14 or $1,060.50. This would represent just that much more profit to the sheep owner and would go a long way towards paying the summer operating expenses of a band of ewes and lambs.

The above increase in the weight of lambs when handled under the bedding-out system is primarily due to the following factors: (1) The ewes are on fresh feed every day with many different kinds of plants to select from, and, as a consequence, their milk supply is proportionately higher than the ewes which are forced to eat feed which has been already grazed over or feed which requires one to three miles trailing each day in order to utilize it; (2) the loss of ime and energy consumed in trailing from an established camp is

entirely eliminated; (3) the ewes and lambs are in most instances allowed to graze at all times just as openly and quietly as possible, giving them the greatest possible range freedom in the selection of their feed with the least amount of dogging, trailing, and running taking place, and (4) the ewes are allowed to choose range forage conducive to the greatest milk supply and production of wool and mutton.

MILK PRODUCTION OF EWES AS AFFECTED BY TYPE OF RANGE FORAGE

The daily milk yield of the ewe has a very marked influence on the growth of the lamb. When a lamb is first starting out in life it takes from its mother considerable fat, which is known on the range as "mother tallow." It makes its most rapid growth during the early period of its life, and the growth of the first month or six weeks is mainly controlled by the supply of milk produced by the ewe. After this period has passed the lamb gradually begins to eat appreciable amounts of forage, so that it is not nearly so dependent upon its mother.

The amount of milk produced by the ewe varies with the different breeds, with individuals of the same breed, the manner in which they are handled, and the kind of forage they are forced to graze. Ordinarily sheep prefer succulent weeds and will make the greatest improvement on this type of forage. A grass range is used most effectively when it is grazed by cattle. In order to determine what effect different types of range forage would have on the production of milk, two ewes and lambs of Rambouillet breeding were selected for study. The lambs were kept away from the ewes except at stated intervals when they were allowed to suckle their mothers. The ewes were first grazed on a range where the feed was mainly grasses and which was becoming coarse and more or less dry. The average milk production of the ewes on this type of range was 1.6 pounds per day. Shortly they were moved to a range which supported succulent grasses and weeds, and the milk supply immediately advanced to 2.1 pounds per day, an increase of .5 of a pound of milk over what it formerly was. The gains in the weights of the lambs were not considered, for it was necessary to keep the lambs in camp while their mothers were out on the range grazing, and this condition was so abnormal that they did not do well. However, it illustrates the importance of the various grazing types for the production of milk which in turn controls to a large degree the steady and fast growth of the lamb.

Thus, from the above it is clearly apparent that the continued rapid growth of lambs requires a range supporting an abundance of succulent forage. Camp-tenders and sheep-herders should therefore utilize their range and select their grazing camps so that the early range will be used first, keeping the higher camps and the areas along streams for use during the hot weather of July and August. Too often range which should be used later on in the season is grazed off early; and during the hottest period of the summer the sheep are forced to eat dry feed, oftentimes going without any shade. As a result, the milk supply of the ewe is materially diminished and the lambs do not make the growth that would have been

Figure 9. Tail-end herding taking place. Turn the leaders and do not try to make the slow-trailing sheep keep up with the fast-trailing leaders. Note massed formation at rear of band.

made if their mothers had been given the opportunity to shade up during the hot part of the day and had been allowed to feed upon the late-maturing succulent range forage at the proper time. The use of the range forage so that shade can be produced for the ewes and lambs during the hottest part of the grazing season, with green succulent feed near water, is not given the attention it should receive in the management of sheep on Nevada's ranges.

EFFECT OF TRAILING ON GROWTH OF LAMB

The effect of trailing long distances in order to get to and from fresh feed is well illustrated by the following case: A camp-tender had failed to move the herder's camp for eleven days and the range was badly overgrazed in the immediate vicinity of the camp, so that the ewes and lambs were forced to trail approximately 1½ to 2½ miles to get to fresh feed. During this period of long trailing to get to fresh feed three lambs were weighed in order to determine just what gains they were making when being forced to trail so far each day. The three lambs weighed 49, 55¾, and 56½ pounds, respectively. Each morning for four days they were weighed, and it was found that their average increase was .25 of a pound per day. With their mothers and the other animals in the flock they were moved and put on fresh green feed and the long trails eliminated.

They commenced to gain flesh immediately. Four days after the change of feed the three lambs had made an average daily gain of .32 of a pound, an increase of .07 of a pound per day over what they were making when compelled to make the long daily trail. This material increase in daily growth was caused by the change in the character and abundance and nearness of the feed. The long daily trails to fresh feed and back had prevented the ewes from giving the necessary amount of milk for the continued rapid growth of the lamb and had kept both ewes and lambs down in flesh; this was shown by the condition and appearance of their bodies. If this practise of maintaining a central camp from which and to which the ewes and lambs were forced to trail each day had been continued for a grazing season of 100 days, it would have meant the production of a lamb weighing on the average 7 pounds less than a lamb which had been allowed to bed down with its mother wherever they were on the range at night. Seven pounds each in the average flock of 1,500 lambs means 10,500 pounds of flesh and wool. This item is certainly worth considering, more especially when it is multiplied by the hundreds of thousands of lambs produced annually on Nevada ranges.

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RANGE PLANTS POISONOUS TO SHEEP AND CATTLE IN NEVADA

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RANGE PLANTS POISONOUS TO SHEEP AND CATTLE IN NEVADA

INTRODUCTION

In Nevada each grazing season brings the news that large numbers of live stock have been poisoned on the sheep and cattle ranges. This is due largely to ignorance on the part of the men actually handling the stock, since they fail to recognize our common poisonous plants. In very many instances the plant causing the loss was thought by the herder to be entirely harmless. It is hoped that the facts presented in this bulletin, with the illustrations, will help to meet this need of definite information about deadly range plants.

Most of the information presented in this publication was obtained from the following sources: (1) Feeding tests by Dr. Edward Records and Dr. Stephen Lockett, of the Department of Veterinary Science, University of Nevada, gave information about the symptoms shown by animals poisoned by eating lupine, rabbit brush, goldenrod, and other plants. (2) Chemical studies by Dr. C. A. Jacobson, of the University of Nevada, gave information about the nature of the poisonous matter contained in certain range plants and the part of the plant which is most poisonous. (3) Field observations made by the writer on ranges in Nevada and other Western States gave much information upon the growth and appearance of poisonous range plants and their importance to our livestock industry.

Because a large percentage of our sheep herders are foreigners who read no English, a part of this bulletin has been translated into Spanish. It is the sole purpose of this publication to give Nevada stockmen and herders practical information, in simple language, about the poisonous plants which are responsible for the greater part of our livestock losses, and to suggest methods of handling by which these losses may be reduced.

PRINCIPAL POISONOUS PLANTS OF NEVADA

Within the State of Nevada seven groups of plants cause most of the losses of live stock. They are: Death Camas, Larkspurs, Water Hemlock, Rabbit Brush, Lupines, Western Goldenrod, and the Locos. Those of less importance are: False Hellebore, Wild Cherry, and Aconite. Some of the groups contain several kinds or species, but, as their general appearance and poisonous properties are much the same, it is not important to distinguish them on the range.

Any of the first seven may fairly be called poisonous plants; that is, plants which cause serious illness or death, either immediately, or else after a time because of the cumulative action of the poison contained in the plant.

LARKSPURS

(*Delphinium* Spp.)

Description of the Plant.

There are two kinds of larkspur on the Nevada ranges; they are called tall larkspur and small larkspur, the latter being sometimes known as purple larkspur.

The tall larkspurs are erect branching plants from two to six feet high. The roots are large and deep set, more or less woody, supporting one or more crowns from which the stems are produced. A leaf is shown in Figure 1; all the divisions or main ribs spread out from the end of the leaf stem like a hand with outstretched fingers. The flowers of the poisonous larkspurs are of various tints of blue or purple, and have a very characteristic shape, due to the development of a spur-like structure on the upper sepal as shown in Figure 2.

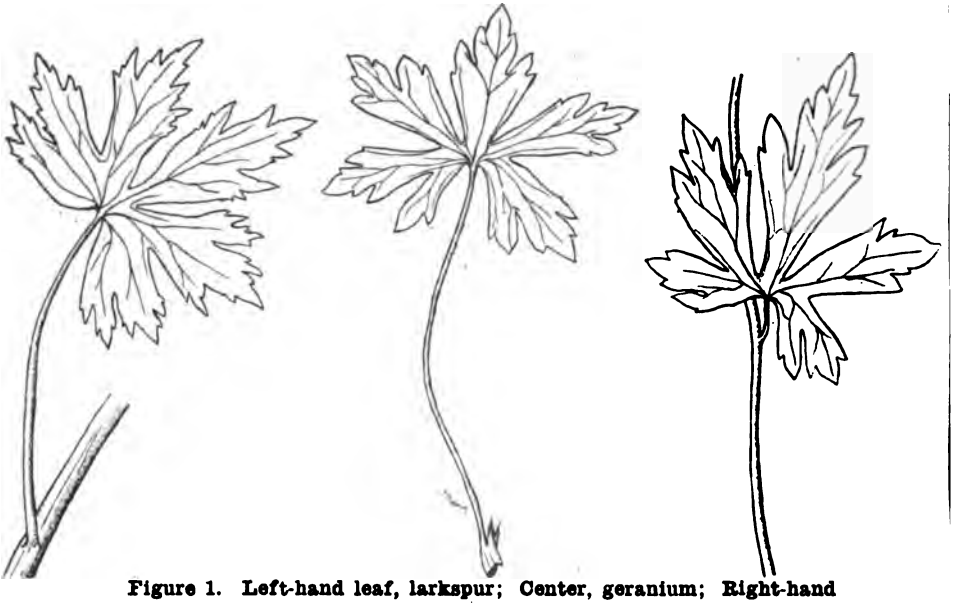

Figure 1. Left-hand leaf, larkspur; Center, geranium; Right-hand leaf, monkshood.

The small larkspurs have single stems or at the most only a few. On the Nevada ranges they grow from 9 to 12 inches tall. The typical small larkspur is show in Plate I.

Distribution and Habitat.

Larkspurs are found on practically every range for cattle and sheep in the northern half of Nevada. Due to the extreme dryness in the southern half, the larkspurs are scarce, and do not cause serious losses.

The tall larkspurs grow in well-drained, moist, loamy areas along the creek bottoms, in the mountain parks, or in the clumps and groves of quaking aspen which are so common on the most valuable range in the eastern part of the State. They grow at altitudes ranging from 4,000 to 11,000 feet.

The small larkspur grows on range varying between 3,000 and 7,000 feet in altitude, where the soil is well drained, not excessively moist,

Plate I. LARKSPUR. (Consolida real.)

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and usually in full sunlight. Thus our mountain foothills and the bordering sagebrush range form the typical country of the small larkspur. It does grow, however, to as high an elevation as the tall larkspur and is often a typical plant of the weed and park areas of the higher elevations. However, it is not much of a menace on the higher elevations because it is not abundant in the whole mass of palatable vegetation, and there is little chance that an animal will eat a fatal quantity.

Other Plants Which Are Commonly Mistaken for Larkspur.

The two plants with which the larkspurs are most commonly confused are the wild pink geranium and the aconite. When the pink geranium is commencing its spring growth it resembles the tall larkspur very closely. However, on the lowest part of the stem of the leaf of the geranium there are the two small pointed appendages which are shown on the center leaf in Figure 1; and these are not present on the leaf stem of

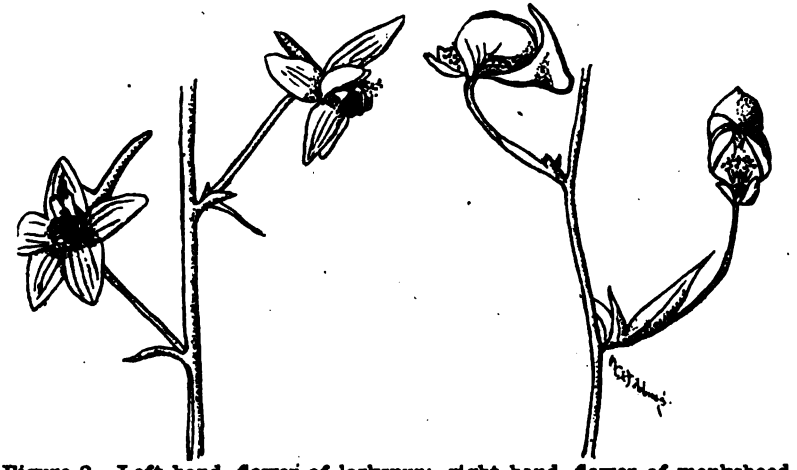

Figure 2. Left hand, flower of larkspur; right hand, flower of monkshood.

the larkspur. Further, upon squeezing the geranium leaf it usually produces the typical geranium odor which, of course, is not present in the larkspur leaf. The geranium leaf is usually covered with a growth of small fine grayish hairs, while the leaves of the larkspur are usually covered with a white surface coating easily rubbed off, much like that on plums and grapes.

The aconite, or monkshood as it is sometimes called, differs from the tall larkspur in that the upper leaves of the aconite plant are much more numerous and the leaves have very short stems as shown on the right-hand leaf in Figure 1. Instead of the flowers being spurred as in the larkspur, they are hooded as shown in the right-hand flower of Figure 2; this gives it the common name of monkshood.

Seasonal Growth.

No dates can be set for the time in the spring when the larkspur begins to grow. The tall larkspur on the lower elevations usually commences to grow during the latter part of April and, if the moisture conditions are right, it will last until late in August or early in September. For every increase in elevation of 1,000 feet the growth of

the larkspur plant is retarded by from ten days to two weeks. Thus, a kind of larkspur which might be in bloom on a 5,000-ft. range on July 15 would not be in bloom on a 6,000-ft. range much before August 1.

In a dry hot season, in Nevada, the larkspurs will start growth, blos-

Figure 3. Geranium. This plant is commonly confused with the tall larkspur during early spring.

som, and ripen their seeds much earlier than if the season were wet and cold; evidently climatic conditions have a very important influence upon the length of the time when larkspurs are capable of causing loss on the range.

On an average the small larkspur comes into bloom from six weeks to two months earlier than the tall larkspur. The small larkspurs are essentially early blooming and early maturing plants. They soon die to the ground after producing flowers and seeds, and cease to be dangerous late in the spring.

Animals Which Are Poisoned.

Sheep. From all field observations and feeding tests it can be safely stated that the larkspurs have no ill effects on sheep. On the other hand, they are more or less palatable, depending upon the variety and abundance of other species with which they are found growing.

Horses. Under ordinary range conditions horses do not relish larkspurs and they seldom eat enough at any one time to cause serious trouble.

Cattle. The larkspur in Nevada probably causes more loss among cattle than all other poisonous plants. Each year on most of our cattle ranges a large number of animals are fatally poisoned by larkspur.

Amount Necessary to Cause Death.

The amount of larkspur necessary to cause death varies with the age of the plant, the condition of the animal, and the individuality of the animal.

The larkspurs are most poisonous during early growth. During April, May, and June it takes much less of the plant to cause death than it does later when the plant is older. The tall larkspur is not poisonous after it has blossomed, and it may be reasonably safe to graze cattle on a range where this larkspur grows if the animals are turned on after most of the plants are through blooming. The seeds of the tall larkspur are its most poisonous part. However, cattle very seldom eat the seeds.

The small larkspur is poisonous through all of its growth; but immediately after blooming it dries up and disappears from the range, so that it is not dangerous after late spring.

Feeding experiments have shown that a steer must eat an amount of larkspur equal to from 2½% to 3% of its body weight in order to be fatally poisoned. An animal weighing 800 pounds would have to eat approximately 25 pounds of either the tall or the small larkspur. Evidentally the larkspurs are not violently poisonous, for to cause death a surprisingly large amount of the plant must be eaten.

Symptoms.

Sheep are never poisoned by larkspur and horses very rarely. Cattle poisoned by larkspur show the following symptoms:

On the range usually the falling of the animal is the first symptom which indicates that it has been feeding on the larkspur. However, most animals after going down the first time get up again and walk with the hind legs spread quite widely apart with a more or less staggering movement. There is little or no action in the joints of the legs, the walking movements being extremely stiff.

When the animal falls it goes down in a typical manner; usually the front legs give out first and the animal then supports itself from going clear over by resting the chin or the side of the head on the ground. In this position the hind legs are usually spread quite far apart. In severe cases the animal lies flat on the ground, raising the

head up and down; in less acute cases it will lie with the head erect. When standing there is a pronounced quivering or muscular trembling over the entire body, especially noticeable in the muscles around the nose and mouth. The spasmodic contractions of the muscles are also very clearly seen around the shoulders, hips, and flanks. There is frequently a belching of gas and an attempt on the part of the animal to vomit. There is usually considerable drooling or "slobbering." Constipation is almost invariably present.

Treatment.

A large percentage of the animals poisoned by larkspur on the range are already dead before they are discovered. Most of the animals which may be treated or cared for are the ones which are poisoned when being trailed from one range to another, or during the driving operations of a round-up.

After an animal goes down it should not be disturbed at all. If it has fallen on uneven ground the head should be placed higher than the body, to allow it to breath more easily. The rough-and-ready method of treating the animal by bleeding should be abandoned; for all experience on the range shows that bleeding only produces weakness and makes recovery less probable. If a steer tries to vomit we may usually safely conclude that it has eaten a fatal dose of larkspur and that nothing can be done to save it. However, the chances for recovery in most cases are good if the animal is allowed to remain just as quiet as possible and is given the following treatment, which was developed by Dr. C. Dwight Marsh, of the Bureau of Plant Industry, United States Department of Agriculture, who reports very satisfactory results from its use:

Physostigmin salicylate	1 gr.
Pilocarpin hydrochlorid	2 gr.
Strychnine sulphate	½ gr.

If losses are taking place each cowboy should be supplied with this remedy made up in tablet form. It can be secured from any druggist. The treatment is administered in the same way as though the animal were being vaccinated for blackleg. A four-dram hypodermic syringe should be provided for this operation. The tablet must be all dissolved and administered as a single dose. The dose should not be repeated. If possible, a bottle of boiled water in which to dissolve the tablets should be carried in the saddle bag. If it is not convenient to use boiled water, then use any clean clear water available. The essential thing is to get the tablet dissolved in clean water and injected under the skin of the animal.

Methods of Handling to Reduce Losses from Larkspur.

On many ranges the tall larkspur grows in small patches; it is these small patches that cause a high percentage of our losses. Where the larkspur is found growing on such well-defined areas, a practical method of preventing loss is by grubbing it out. The cost of grubbing will depend on: (1) The average wages of the men employed; (2) the cost of transporting men to the infested area; (3) the abundance of the plants and their distribution; (4) the nature of the soil, whether loamy, gravelly, or rocky; and (5) the type of vegetation the larkspur is associated with, whether weeds, creek brush, sidehill brush, quaking

aspen areas, etc. On the most difficult areas the cost of grubbing should not exceed $12 to $15 per acre, and the average cost should be approximately $5 to $8. Where grubbing can be done, it is much cheaper in the end than fencing or establishing drift fences because (1) there will be no waste of forage through nonuse; (2) the first cost of fencing will exceed the cost of grubbing; (3) the yearly cost of fence repair is eliminated; and (4) the rebuilding of the old fence when it is worn out is obviated.

The grubbing should be done so thoroughly that no plants are allowed to remain to reinfest the area worked. The larkspur should be cut off at least 6 inches below the surface of the ground, and the deeper the cutting the more effective will be the work. Not only the main roots but also all well-developed side roots should be taken out of the soil because if left in the ground they will produce new growth. A second grubbing the next year will be necessary, but the expense will be very light, and practically speaking all the plants will then have been eliminated from the range.

On certain ranges it is practical to first graze larkspur-infested areas with sheep. However, the sheep should be confined as closely as possible to the larkspur patches because if they graze the rest of the range there will not be much feed left for cattle. The cattle will then be forced to eat what they can find and they will graze all the larkspur patches again. The object of first grazing a larkspur-infested area with sheep is to remove the tempting larkspur plants and to give the other range plants a chance to grow. Also, when the larkspur is eaten off short before it is very large it is set back severely and will not make much growth that season. There is little or no use in trying to eliminate losses from larkspur from a range by grazing with sheep, unless it is done early in the spring. If it is not done at this time, the tall larkspur will grow to such a height that the sheep will only remove the lower part, and the plant will still be tempting to cattle; and, even though all the lower leaves are stripped off by the sheep, the upper leaves, flowers, and seeds will still be produced.

Because it takes so much larkspur to kill an animal, the chance of fatal poisoning will be greatly reduced if the larkspur patches are first grubbed out or grazed.

On all ranges there should be plenty of salt where the cattle can get it all the time. When larkspur is growing on the range, the salting grounds should be placed where they will be away from the larkspur patches. This will help to keep the animals from bunching and feeding where the larkspur plant is abundant. The salting grounds should be continuously changed, so that no part of the range will be badly overgrazed. After the larkspurs have blossomed the infested areas may be grazed with a minimum chance of loss taking place.

The choice of range plants is greatly influenced by the hunger of the animals. When the stomach is empty and the animals are very hungry they will eat many plants that they ordinarily would not touch. On a list of plants pleasing to the taste of cattle, the larkspur will not be among the first if there is much variety of forage present. When eaten in small quantities the larkspur causes no real ill effect, but if eaten in large quantities by hungry cattle some of them will undoubtedly get enough to cause death. Therefore, it should be a general practise never to drive stock over larkspur country while

their stomachs are empty. At all times cattle should have the greatest possible chance to select the plants they like. This means that fast trailing and hazing from one range to another must be cut out if losses from poisonous plants are to be kept down.

Herding Cattle Away from Larkspur Patches.

It is more or less impractical to herd cattle away during the entire grazing season from a larkspur range, but extreme care should be taken for the first two or three weeks that the animals are on the range; for during this period they are frequently in very poor condition, some even "skin poor." In this state they will eat any and all plants, including poisonous kinds, a good many of which they will not touch later, when they have mended or increased in flesh and their ravenous hunger has been satisfied. It should always be remembered that a poor, weak, hungry animal will eat many plants that it will not touch when well fed and in good condition.

Figure 4. Death Camas bulb, showing thin, papery, brown coats.

Figure 5. Death Camas, showing typical manner of growth on the range.

DEATH CAMAS

(*Zygadenus* Spp.)

Death camas is the name by which this plant is known in most places on the range, although it is sometimes called mystery grass, poison wild onion, poisonous sego, poison camas, and lobelia. Death camas, however, is the recognized common name and is the one which should be used.

There are several forms of death camas in Nevada; but they are all so nearly alike both in appearance and their effect upon range animals that one description of the general form of the death camas is considered sufficient.

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Plate II. DEATH CAMAS.

Description of the Plant.

The death camas is an erect plant producing from five to seven fully formed grass-like leaves. It grows from a layered bulb set from 2½ to 6 inches deep in the soil. The bulb is from ½ to 1¼ inches thick and is covered with thin papery brown coats as shown in Figure 4. The leaves are from 6 to 18 inches long by a little less than ½ inch wide and are grass-like in appearance with a projecting ridge like the keel of a boat on the under side. They are much more succulent or juicy and thicker than the common grass leaves. There is no well-defined stem, the leaves appearing to rise from near the surface of the ground. The flowers are greenish-yellow or whitish, about ¼ inch across, and are produced in a flower cluster from three to ten inches long. The lower flowers ripen first and produce seed on the lower ranges during the latter part of May and the first part of June. The seeds which are formed do not grow until the next spring, when they produce a leafy grass-like plant which, however, has no bulb at first, but develops one later in the season. The second year this leafy grass-like plant sends up the typical death camas leaves and flower stock as shown in Plate II.

Distribution and Habitat.

This plant is to be found on practically every stock range in Nevada. It is more abundant in the northern part of the State than in the southern half. The areas upon which it grows are invariably moist, during the spring, and the typical grazing types in which it grows are: (1) sagebrush, (2) grass, (3) semimeadow areas, and (4) typical weed range where the vegetation consists largely of showy flowering plants. It does not grow in the shade under standing timber. It is found on practically all of the mountain foothills, the high open mountain park areas and in the sagebrush country of northern and western Nevada.

The time when death camas starts to grow in the spring varies with the season and also with different exposures and different soils. It is sometimes found as early as the middle of March. The plant makes its appearance first on sandy soils and on southern exposures. On the dark, loamy and clay soils its growth is much retarded, probably because these soils are moist and consequently they warm up less readily. If the weather is fairly warm the death camas commences to grow from ten days to two weeks after the snow melts out in the spring and it is soon high enough to cause loss. On the lower ranges by the latter part of June it has usually died down.

Plants Commonly Mistaken for Death Camas.

The death camas is most commonly confused with the wild onion. The bulb and leaves of the death camas, however, have no such smell as the onion. All the flowers of the wild onion grow out from one point at the tip of the stem, as in Figure 6, while the flowers of the death camas grow along the sides of the stem, as shown in Figure 6.

Animals Which Are Poisoned.

This plant is poisonous to all classes of stock, but more especially to sheep. Horses very seldom die as a result of eating it, though cattle are sometimes lost in the spring when they are turned out in very poor condition, or when they are being driven over badly infested areas. While being trailed they are usually extremely hungry and will nip and bite at all plants whether good or bad.

Losses of live stock from this plant are heaviest on a range that has been overgrazed. On such a range the death camas usually starts much earlier than the other plants because it has not been set back by the heavy grazing and consequently it has a greater amount of reserve food material with which to start plant growth. Further, the highly palatable and nutritious plants have all been removed, leaving only the undesirable and poisonous kinds. Consequently the probability of poisoning on such a range is greatly increased.

Parts of the Plant Which Are Poisonous.

All parts of the plant are poisonous. Ordinarily the part eaten is the leaves; which are equally as poisonous as the bulb. The seeds are

Figure 6. Death Camas on the left, and wild onion on the right.

also poisonous, but are very seldom eaten. The entire plant is poisonous throughout its period of growth.

Amount of Death Camas Necessary to Cause Death.

The amount of the death camas which must be eaten in order to cause fatal results depends upon (1) the individuality of the animal; (2) the weight of the animal, and (3) the condition of the stomach when the plant is eaten. A ravenously hungry animal is poisoned much more easily than one with a full or partly filled stomach. On the range a mature ewe weighing approximately 100 pounds must eat from 1½ to 5 pounds of the plant to cause fatal poisoning. For lambs it takes a correspondingly less amount.

Figure 7. When sheep graze openly and quietly on the range they show great care in the selection of the forage they eat. Thus the losses from poisonous plants are kept down to a minimum.

Symptoms.

When sheep on the range are poisoned by death camas the first symptom noted is that some of the sheep begin to straggle along with a decided indisposition not to graze with the other animals in the band. The head is dropped, and with most animals salivation or slobbering at the mouth takes place, accompanied by vomiting in the case of those badly poisoned, although many animals that have eaten a fatal dose do not salivate as freely as some which have eaten only sufficient to make them sick. The manner of walking is very irregular, both the fore and hind legs being affected, more especially the hind legs. When the animal falls it goes down head first, oftentimes resting for a short period on its knees. After the animal is down and cannot get up, the majority of them go off into a state of profound insensibility resembling very deep sleep, from which they cannot be aroused, and in this condition they die.

On a range in eastern Nevada, where practically the only vegetation was sagebrush and death camas, five steers were poisoned by death camas, and the symptoms were practically the same as those just given for sheep. However, cattle are very seldom poisoned by eating this plant because (1) it is not highly palatable and (2) it does not usually occur in a sufficient abundance so that the animals will be able to get a fatal dose.

Remedies.

There are no recognized remedies at the present time. The best treatment known is to let the animals entirely alone, disturbing them just as little as possible.

Methods of Handling to Reduce Losses from Death Camas.

When grazing openly and quietly on a range, as in Figure 7, sheep show great care in the selection of the forage they eat. However, when they are being trailed from one place to another they are deprived of the privilege of selecting and choosing their forage, with the result that without this chance of selection they eat everything that is not absolutely objectionable. If the death camas is on the range, and it usually is, they may eat so much of it that they get more of the poison than they can cast off, and death is the result. It should always be remembered that when a sheep is hungry it usually eats the whole plant it is grazing on at once; but only the tender and juicy parts such as the leaves and young stems, the most choice portions, are nipped off when it is not exteremely hungry or when it is allowed to graze with an opportunity of selecting its forage.

Thus, in order to avoid losses on a range, where death camas is growing, sheep should be so handled that they are never at any time extremely hungry. If they are being trailed from one range to another, it is best to allow them to graze for an hour or two in the morning just as openly and quietly as possible before starting to move them. This will allow all the animals to fill quite completely; and they will then use greater care in the selection of their forage for the remainder of the day. This would not be the case if they were started on the trail immediately after leaving the bed-ground.

Another very important point is to get the sheep off the bed-ground

just as early as possible in the morning. When a sheep beds down at night it is usually full and contented. By morning it is beginning to get rather empty, and the longer it is kept on the bed-ground the hungrier it becomes; it is then far more apt to be poisoned when it gets out on the range where the death camas is growing.

In most cases of death camas poisoning so far observed, the animals were poisoned during the forenoon. This is due to the fact that the palatability of the plant decreases as the stomach becomes full. Thus a plant which may seem to be highly palatable and to be relished during the morning hours frequently is not touched later in the day. This is quite true of the death camas. It is grazed chiefly during the early morning hours, and is seldom touched when the stomach begins to be full. Therefore it is highly important that the sheep should be so handled during the early morning hours that they will have the greatest freedom in the selection of their range forage; if possible, during this part of the morning they should be grazed on range free from death camas, or where it has only a scattering growth.

In Nevada the prevailing method of handling sheep, especially in the spring of the year, is to establish a main camp from which the sheep are grazed daily until all the feed in the immediate vicinity of the camp has been eaten out for a radius of two or three miles. This necessitates long daily trailing back and forth in order to get from range that has already been grazed to fresh feed. Thus the sheep trail over the same ground each day until all the forage on the range around the bed-ground is completely eaten off. This method of handling can only result in all plants being eaten, whether poisonous or not; for the most palatable ones are first grazed, and as these plants are removed the less palatable ones are left to be grazed including, of course, the death camas. In order to avoid losses resulting from these improper methods of handling sheep, they should be allowed to bed down wherever they happen to be when night comes. They will then always be on fresh feed in the morning. The variety of forage from which to choose will be much greater and the chance of poisoning will be greatly reduced, providing the animals are gotten off the bed-ground early in the morning and are allowed to spread out to graze openly and quietly, each ewe with her lamb. Close-bunched grazing, running, trailing, and massing should never be allowed, not only in order to keep the losses down, but also for the good of the ewe and her lamb and for the most full and effective use of the range forage.

After a sheep has been deprived of salt for a week or ten days it develops an abnormal or depraved appetite, with the result that it will eat many plants which ordinarily it would never touch. Therefore it is of the greatest importance that sheep be regularly and abundantly salted, so that the appetite will remain normal and the tendency to eat obnoxious or poisonous plants will be reduced. This means that they should have salt every day, and if it is not practical to salt daily, salt should be supplied at least every three days. A sheep under ordinary range conditions will eat approximately ½ ounce of salt per day, or 3 pounds per day to every hundred head. This does not make any allowance for waste, which, of course, varies according to the manner in which the salt is distributed to the sheep.

LUPINES

(*Lupinus* Spp.)

The lupines in Nevada are known by various common names, being improperly called blue bean, wild bean, wild alfalfa, blue pea.

Description of the Plant.

The lupines belong to the pea family, and are erect plants from six inches to three feet high, depending upon the species, the altitude, the soil, and moisture conditions. Most of the species in Nevada grow year after year from the same heavy deep-set roots, which produce several stems, the leaves of which are long stemmed and are divided into from four to fifteen small leaf divisions, all spreading from the end of the one leaf stalk. The flowers are borne in long clusters and are shaped like those of a pea. The colors are various shades of blue,

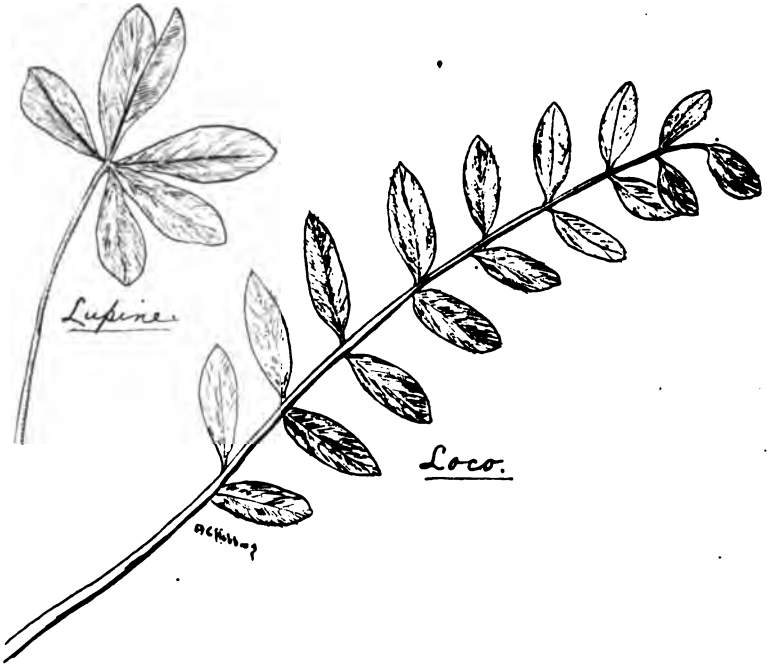

Figure 8. Showing the arrangement of the leaflets of the lupine on the left and a typical leaf of the loco on the right.

white, pink, or yellow. The pods contain one or more seeds and are usually covered by a growth of many small gray hairs. This hairy growth also is usually found on the upper surface of the leaves, giving the plant a typical grayish appearance. The lupine plant may be found in blossom from early summer until late fall. The largest number of flowers, however, are produced during July and August. A typical lupine plant is shown in Plate III.

Distribution and Habitat.

The lupine is one of the most widely and abundantly distributed of all the weeds or showy flowering plants found on the ranges of Nevada. It is found on practically all the low elevations and grows to an alti-

Plate III. LUPINE. (Lupino.)

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tude of 10,000 feet. It grows on all types of soil, except those which are excessively wet or dry.

Plants Commonly Mistaken for Lupine.

The lupine is frequently confused by many stockmen with several plants, the most common of which is loco. However, the lupine may be readily distinguished by the arrangement of the leaflets, as shown in Figure 8, where they all arise from the end of the stem, while in the case of the loco the leaflets are arranged along the main axis of the leaf with one odd leaflet borne at the end.

Animals Which Are Poisoned.

Under certain range conditions this plant may be poisonous to all classes of stock. However, the heaviest losses take place when sheep graze upon it after the seeds have been formed within the pods. Horses are very found of lupine, but in order to be poisoned they must graze exclusively upon it for a rather prolonged period; this seldom occurs on the open range. It is not grazed with any degree of eagerness by cattle, yet losses have been reported on certain ranges in the late fall where this plant was the only one to be found on the range. Lupine poisons very few horses and cattle under Nevada conditions.

Sheep will always graze upon the grasses and succulent weeds before eating lupine. However, in the fall of the year when the other feed is becoming scarce and what little is left is dry, the lupine is usually still green and in pod. Sheep then graze upon it with disastrous results.

It seems that the lupine becomes more palatable after it has been frosted, but usually by this time of the year most of the seeds have dropped to the ground and of course there is then little or no danger from poisoning. Under such range conditions before sheep are allowed to graze on lands where lupine is common it should be carefully examined to see that it has no seeds in its pods. If there are still seeds in the pods, the sheep should not be allowed to graze upon it unless there are other plants on the range which will be eaten in preference to it.

All over Nevada there is a small weevil which feeds in the pods of the lupine and destroys the seeds. The pods may look as though they contain seeds, but upon close examination they are found to be seedless and of course the chances of poisoning taking place are very slight.

Parts of the Plant Which Are Poisonous.

Under certain range conditions which have not been definitely determined the leaves and the tops of the lupine plant have been known to cause death. However, the majority of the losses on the range have taken place after the lupine plant has blossomed and produced its seeds. (See Figure 9.)

In most cases after a sheep has eaten a large amount of the pods and seeds, it does not chew its cud before the typical poisoning symptoms appear. However, after the symptoms do appear the animal poisoned may die in a very short time or it may linger for one or more days before succumbing or getting entirely well. Thus, sheep may feed on a lupine patch one day and yet they may not be sick until the next day, when they may be grazing on country entirely free from any

or all poisonous plants. This accounts for the fact that losses often are reported on a range entirely free from all recognized poisonous plants. A question that often bothers the range man is: How can a band of sheep graze and fill up on lupines at one time with no ill effects; yet at another time when they do the same thing heavy losses follow? This may be explained by the fact that the poison from the lupine is excreted by the kidneys and is thrown off as soon as it is liberated; in order to cause death or ill effects the animal must get

Figure 9. A lupine plant in full pod. When the plant is in this stage most of the losses from poisoning take place.

more of the poison at one time than it can cast off immediately, with the result that the excess of poison is left in the system, causing the typical lupine symptoms and possibly death.

Amount of the Plant Necessary to Cause Death.

The amount of the plant that must be eaten before death will take place is an extremely variable quantity due to (1) the individuality of the animal; (2) the weight and general health of the animal; (3) the

species of plant that the lupines are associated with; (4) the condition of the stomach of the animal when the lupine is eaten; and (5) the kind of lupine eaten.

The most accurate feeding tests so far made show that it takes from ¼ pound to ½ pound of the seed to cause active acute poisoning or death in a sheep weighing approximately 100 pounds, and about 1½ pounds of the pods and seeds to produce the same serious effects. Very rarely are any animals poisoned by eating the leaves and stems, although some losses from this source have been reported.

Symptoms.

Probably the most common symptom of lupine poisoning is the manner in which the animal breathes. In acute cases of poisoning the animal breathes with difficulty and there is usually a frothing at the mouth. During these periods of difficult breathing it will throw itself about violently with great mental excitement, often running in no

Figure 10. Sheep in first stages of lupine poisoning.

definite direction, bumping into other anmals in the flock or against any obstruction that may happen to be in its way, such as brush, trees, or large rocks. When the roof of the mouth is examined a typical blue appearance is usually seen. A large number of animals die during these periods of extremely difficult breathing which make the animal appear as though it were in violent convulsions. On the other hand, some of the animals may go into a very deep sleep from which they never awaken. In less acute cases of poisoning the breathing is very labored and the animal may stand or lie down in a condition of deep sleep. The drooping of the ears is another typical symptom, usually accompanied by the animal pushing or butting its head against other near-by animals or objects. After an animal has passed through one of these periods of extremely difficult and labored breathing it often stands trembling all over. Figures 10, 11, 12, 13

show the characteristic attitudes assumed by a sheep poisoned by lupine.

Treatment.

There are no remedies which have given satisfactory results in treating a large number of sheep poisoned at the same time, as is usually the case on the range.

Methods of Handling to Reduce Losses from Lupine Poisoning.

Practically speaking, almost all the heavy losses which take place on the range as a result of sheep eating the lupines are due to mismanage-

Figure 11. Sheep in second stage of lupine poisoning.

Figure 12. Sheep in third stage of lupine poisoning, in which they usually die.

ment of the animals and to a lack of information regarding conditions under which poisoning almost invariably takes place.

When sheep have been driven hard or shipped or penned they are very hungry. If they are then turned on to a lupine range where the plants are in flower and pods, they will eat the lupine plant as rapidly as possible, especially the pods and seeds, consuming enough of this part of the plant to cause death. Therefore, a rule which should never be violated is, never to turn ravenously hungry sheep on any lupine range, for losses will be almost certain to follow. The most disastrous range losses have taken place where this rule was not observed.

During late summer and early fall the lupines grow abundantly on

many of the sheep ranges. At this time of the year they usually are in full-pod stage and quite frequently the leaves are green and offer the most tempting forage because the other range plants are dry or else have disappeared. It should be remembered that the seeds are by far the most poisonous part of the plant and at this time of the year sheep are very fond of the pods, for they have a pleasant sweet taste that these animals particularly relish. Therefore, a lupine range in the pod stage is dangerous grazing country, especially if the lupines are the most abundant plants on the range.

Whenever it is necessary to drive sheep for any considerable distance over a range infested with lupines it is always highly important, in order to keep losses down, to first allow them to graze with the greatest amount of freedom during the early morning hours. Then, instead of

Figure 13. Sheep poisoned by lupine. Frequently when poisoned they run in no definite direction, butting into bushes, trees, and other objects.

dogging them and trailing them fast, they should be allowed to spread out just as far as possible and to take their time in crossing over the dangerous lupine range.

WATER HEMLOCK

(*Cicuta* Spp.)

The other common names by which this plant is known in Nevada are cowbane, wild parsnip, and poison parsnip.

Description of the Plant.

Water hemlock is a marsh or water-loving plant, tall and branching, from two to six feet high. The smooth, hollow, green stems grow from

a bunch of fleshy, spindle-shaped roots (Figure 14) which have a series of cross-partitions dividing the interior of the root into small, short chambers, as shown in Plate IV which is a typical water-hemlock plant. The leaves are doubly divided, and each leaflet is narrow, long, and finely toothed along the margin. The flowers are borne in dense clusters at the end of the branches and are greenish-white in color.

Plants Commonly Mistaken for Water Hemlock.

The water hemlock is often confused with certain harmless plants which resemble it closely, not only in the appearance of the upper part of the plant, but also in the root structure. When the root of the water hemlock is cut in two lengthwise, it is easy to see the cross-partitions and small chambers. However, there are a few other plants in Nevada which have the same structure in the roots, notably the sweet anise (*Washingtonia*) and the water parsnip (*Sium*).

Sweet anise does not grow in extremely wet places as does the water

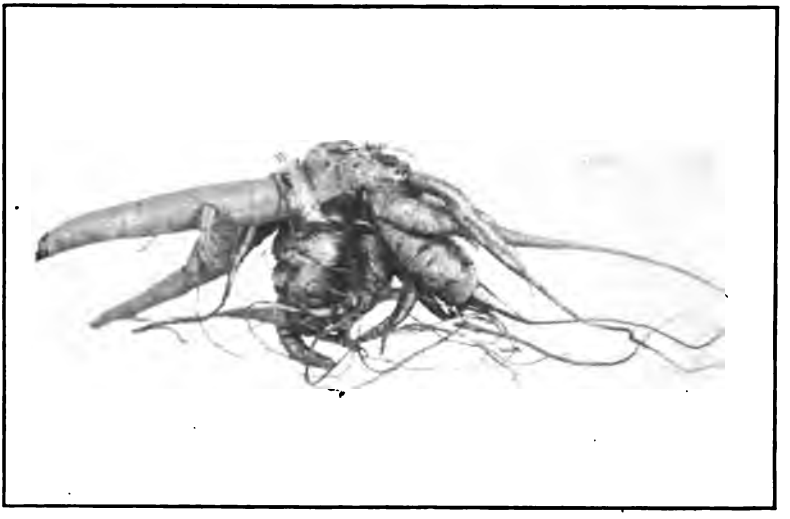

Figure 14. Roots of water hemlock, showing the fleshy, spindle-shaped manner of growth.

hemlock; it is found along mountain creek bottoms and in densely shaded places. The anise leaflets are much broader than those of water hemlock and it blooms during the early summer, while the water hemlock does not blossom until midsummer. Sweet anise is not poisonous to stock and is greatly relished.

The water parsnip grows in wet, marshy places, as does the water hemlock. However, it may be easily distinguished from the water hemlock because the leaves of the water parsnip do not branch, while those of the water hemlock are compound or branching, as is shown in Figure 15.

Distribution and Habitat.

The water hemlock is a typical water-loving plant and as such it is found along the banks of irrigation ditches, streams, in tule swamps, and wild meadow hay land. It has not a wide nor an abundant distri-

Plate IV. WATER HEMLOCK, (Cicuta.)

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bution, but where it grows it causes considerable losses each year. It is never found growing away from extremely moist or wet areas.

Animals Which Are Poisoned.

This plant is violently poisonous to all classes of stock. In Nevada very few sheep and horses are poisoned by water hemlock, but there are heavy losses of cattle every year.

Parts of Plant Which are Poisonous.

So far all of the feeding experiments indicate that the only part of the plant poisonous are the roots. The leaves and stems in large quantities have been fed to sheep and cattle with impunity. It is the most poisonous plant which we have on our western ranges, although it does not cause as many losses as some of the other poisonous plants, due to its restricted distribution and the more or less limited possibility of the animal pulling up and eating the root.

Amount Necessary to Cause Death.

It takes only a very small quantity of the root to cause death. Most of the fatal cases reported were caused with two to three ounces in the

Figure 15. A typical water parsnip leaf on the left, and a water hemlock leaf on the right.

case of sheep and eight to twelve ounces with mature cattle. It is therefore readily seen that the roots contain a violent poison.

Symptoms.

It takes from 20 to 40 minutes for the poison to be absorbed after the plant has been eaten so as to cause the first symptoms, which are frothing at the mouth and pronounced uneasiness with extreme pain, more especially in abdominal region. After falling there is convulsive champing of the jaws and gnashing of the teeth, together with violent convulsions, accompanied by a gradual stiffening of the legs with a bending backward of the head and neck. Quite frequently during the period of violent convulsions the animal will bellow and groan from pain. The pupils of the eyes are dilated and the pulse rapid and weak.

The convulsions are intermittent, some prolonged, others of short duration.

The intervals between the muscular spasms or convulsions grow shorter until the animal becomes unconscious and finally dies.

The poison is absorbed and acts very rapidly, and apparently is cast off quite quickly, for the animal fatally poisoned soon dies, while those

Figure 16. A water hemlock plant showing its typical manner of growth with other vegetation.

which have not eaten a fatal dose soon recover and are, to all outward appearances, well.

Treatment.

At the present time the treatment for water-hemlock poisoning is very unsatisfactory because (1) when an animal eats a fatal dose the poisonous substance contained in the plant is so rapid in its action that death usually results before the animal is found or any treatment can be given; (2) there is no known specific antidote for the poison; and (3) the animal is so excitable when poisoned that to try to give it any treatment in many cases only makes it worse.

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Plate V. WESTERN GOLDENROD.

Methods of Handling to Reduce Losses from Water Hemlock.

The water hemlock has such a limited distribution and abundance that it is easily exterminated on ranges where it causes loss, by simply grubbing it out. The cost of one poisoned steer would usually pay for grubbing out all the water hemlock on several acres because of the ease with which it is grubbed and its limited distribution and abundance. (See Figure 16.) After the plant has been grubbed it should not be left on the range or in the field, but it should be put in a wagon and carried off to some inclosure where stock cannot get at it and where it should finally be burned. In case the grubbing was done on the range the most feasible way to dispose of the plant is to dig a hole and throw in the roots. A fire of dry sticks is then built on the roots and when the fire has burned down the hole is filled. Great care should be taken not to leave any of the grubbed roots on the surface of the ground where stock may eat them.

WESTERN GOLDENROD

(*Solidago* Spp.)

The two species which are definitely known to cause loss are found growing in the wild hay lands, in permanent pastures, and well-drained moist mountain country. They are known botanically as *S. spectabilis* and *S. concinna.*

Description of the Plant.

Under certain range conditions the smaller goldenrods seem to be poisonous. A general description of the small goldenrods should therefore be of greater value than a detailed description of any one kind.

The goldenrods which are known to have poisoned sheep are a foot or more high with undivided leaves. The leaves which are close to the ground taper toward the stem; the leaves on the stem are narrow, two to four times as long as broad, and more or less rounded in outline. The leaves produced close to or with the flowers are small, narrow, and flat. The flowers are yellow; they grow in rather dense clusters at the end of the branch stem. Plate V shows the typical form and appearance of the goldenrod which has poisoned many sheep in Nevada.

Where the Goldenrods Grow.

The goldenrods, especially the low-growing varieties, are found all over the northern half of Nevada. They grow in native hay lands, in well-drained pastures, and in the mountain park and meadow country. They do not grow in very dry country with sagebrush, dry grass, and weeds. While they have a wide distribution, they are rarely found growing in any great abundance over a large tract of meadow or pasture lands.

Animals Which Are Poisoned.

So far in Nevada the only animals poisoned by goldenrod have been sheep, among which there have been several disastrous cases of poisoning. Sheep grazing on goldenrod have been poisoned; others died from eating the dry plants in hay.

Parts of the Plant Which are Poisonous.

Only the upper part of the goldenrod is eaten, more especially the

leaves, the flowers, and the younger and more tender stems. The roots of the plant are not pulled up when it is being grazed.

Amount of Goldenrod Necessary to Cause Death.

We do not know just how much goldenrod a sheep must eat before being poisoned. However, animals have died from eating $1^1/_{10}$ pounds of the green plant. Since some sheep have died from eating dried goldenrod in hay and others from pasturing it where there was an abundance of other plants, it seems that only a small amount is necessary to cause serious poisoning or death.

Symptoms.

The first symptoms noted are a salivation or slobbering accompanied by a constant movement of the jaws and lips. There is also continuous quivering of the ears and head, with recurring unnatural contractions of the body muscles. When these contractions take place they appear as if the animal were trying to shake something off the fleece. There is a pronounced arching of the back during these prolonged shaking spells. The legs are usually close together, appearing as though they were tucked up under the body. Any sudden noise will immediately start a shaking of the fleece as above described. The nervous movements or muscular contractions start in the region of the face and head, pass down the neck and back, and finally affect the legs. After being poisoned, many animals, without any cause, will leave the flock, start off in a dazed condition, stepping high with the front legs, with the head held high and quivering. This erect quivering position is held for a minute or more, when a trembling of the muscles of the neck, legs, and back will commence, with a sudden weakness and unsteadiness of gait, when the animal usually falls and passes into a convulsive state. During and immediately after this condition of the animal the pupils are dilated and the sense of direction and distance is completely deranged. As soon as the convulsive motions have ceased there is a champing of the jaws, with salivation, continued shaking of the head, and a quivering movement in the neck. Practically speaking, all animals poisoned seem to have an uncontrollable desire to seize some near-by object, such as a stick or a stone, and to chew it continuously for hours.

Methods of Handling to Reduce Losses from Goldenrod.

Large losses have taken place from feeding goldenrod to sheep in cured hay. If the hay is to be fed to sheep, the areas upon which the goldenrod is found growing should be determined and the hay from these areas stacked by itself and fed to either horses or cattle, which seem to be immune from the poisonous effects of the plant. Usually the loss which occurs as a result of sheep eating goldenrod put up in cured hay is relatively small at any one time, only a few of the animals dying each day. When such losses begin the hay should be examined immediately, and, if found to contain goldenrod, the feeding of it to sheep should be discontinued. Under certain conditions, not yet definitely understood, it seems that hay containing goldenrod may be fed to sheep without any losses taking place. Possibly this is due to the fact that there is such a small amount of the goldenrod scattered through the hay that none of the animals get a sufficient amount of it at any one feeding to cause trouble.

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Plate VI. RABBIT BRUSH.

When sheep are pastured where the goldenrod is growing, they should be allowed at all times the greatest possible freedom in the selection of their forage. In order to keep their appetites normal, they should be regularly and abundantly salted. Quite frequently the goldenrod grows in dense patches from which it is entirely practical to herd the animals away. In order to do this the herder must be able to recognize this plant easily and to distinguish it from all others. Plate V is an excellent illustration of the general growth and appearance of the plant. When it is cured in the hay the yellow blossoms will usually still be on the plant, so it is fairly easy to find the goldenrod in case any hay is suspected of causing losses.

Figure 17. Rabbit brush, showing its manner of growth on the range.

RABBIT BRUSH

(*Tetradymia glabrata*)

This shrub is now known to be poisonous at certain times of the year and under certain range conditions. It has already caused the loss of several thousand head of sheep.

Description of the Plant.

It is a rigid shrub from one to four feet high with slender spreading branches which are whitened with matted woolly hairs, which fall off each year. The leaves are smooth and green, the main ones being slender and tapering from a broadened and thickish base to a sharp point, while the young leaves are fleshy and pointless. The flowers are yellow and are borne in clusters. Plate VI shows a typical branch of this shrub, and Figure 17 shows the manner of its growth and branching.

The spiny rabbit brush is very frequently found growing with the rabbit brush above described. It is also a shrub from three to four

feet tall with the branches widely set apart and covered with a dense mat of white hairs. Straight or recurved sharp-pointed spines are produced instead of the primary or main leaves of the ordinary rabbit brush.

Distribution and Habitat.

The rabbit brush has a very wide distribution, being found more or less on all of our dry sagebrush areas. It is in evidence on our dry ranges throughout the year. The characteristic vegetation with which it is found growing is sagebrush, bud sage, white sage (*Eurotia*), shad scale (*Atriplex confectifolia*), salt sage (*Atriplex Nuttallii*), and the green sages (*Chrysothamnus* Spp.). It is also found growing quite frequently in pure stands. It has not been found growing on land full of alkali where the sagebrush is replaced by such shrubs as greasewood (*Sarcobatus* Spp.), and a few of the salt sages, sedges, and rushes. It is never found growing in mountain areas where there is a great profusion of grasses and weeds.

Animals Which Are Poisoned.

Under ordinary range conditions this shrub is very seldom eaten by any class of stock except sheep, and they graze upon it only when forced to do so because of a distinct lack of more desirable forage. Therefore the only animals so far known to be poisoned by it are sheep.

Parts of the Plant Which Are Poisonous.

During the spring of the year this shrub produces many young buds and leaves on which the sheep graze, and consequently it is this part of the plant which has so far been responsible for all the losses. In fact the remainder of the plant is so very woody and tough that it would not be eaten by any class of range stock.

Amount of Rabbit Brush Necessary to Cause Death.

From all observations made so far, before being fatally poisoned a sheep has to graze exclusively on this plant for some time, until the stomach is nearly full. The fresh young leaves and buds with the tender green shoots are the portions eaten, but this occurs only when the sheep are very hungry; for these parts are not highly tempting or pleasing to the taste.

The fresh young leaves and buds contain about 2% of potash, a violent poison, which may be the cause of the death of the sheep. Some sheep can eat far more rabbit brush than others without being poisoned.

Most of the losses which have occurred in Nevada were in flocks which were ravenously hungry or in flocks which had been fed all winter in feed lots and were being trailed over a range where rabbit brush grows. Sheep which have wintered down on the desert where the white sage and the bud sage grow abundantly seem able to eat rabbit brush without being injured. This is probably due to the fact that these sheep have been feeding all winter on plants containing a high per cent of potash or whatever the poisonous substance may be which is responsible for rabbit-brush poisoning.

Symptoms.

After a sheep has filled up on the young green shoots the animal first appears to be very dull and somewhat senseless. It staggers and

is weak. When grazing or standing still it may suddenly fall over in an insensible condition, with the head bent or moved to the side of the body. Muscular spasms follow, the eyes are bulged and staring, the breathing is very shallow. When breathing, the nose and face are wrinkled as though the nose were blocked with some obstruction. Grinding of the teeth is fairly common in all animals down, and after a while bloating takes place. Swelling of the ears and head occurs in many cases. Mucus streaked with blood usually flows from the nose. After the animal falls, death usually follows in from five minutes to an hour.

Treatment.

After a sheep has been poisoned by rabbit brush, little or nothing can be done for it. Usually when a flock is poisoned by eating this plant, large losses take place, and, as there may be several hundred sheep down at the same time, individual treatment is out of the question.

Methods of Handling to Reduce Losses to a Minimum.

Losses may be almost entirely avoided by cautious herding. The most important thing to know is that the sheep are most likely to eat

Figure 18. Sheep grazing on an area supporting rabbit brush. Under these conditions poisoning is likely to occur.

this shrub when they are exceedingly hungry or when there is a scarcity of other range forage. (See Figure 18.) The herder should become thoroughly familiar with the appearance of rabbit brush, and when he sees that the animals are feeding almost exclusively on the green tender parts he should, if possible, remove them immediately to a range free from it. He should be able to recognize this poisonous brush at a glance, and should drive the sheep where it does not grow. This knowledge is particularly desirable when the sheep are on the trail or at feeding-places along the railroads, at shearing corrals, or when they have been shipped long distances and are extremely hungry.

When in this condition they eat everything that is not positively objectionable, and as a result, if the rabbit brush is present, they will eat enough of it to cause death. Ordinarily they do not eat enough to do them any harm.

Often, when sheep are moved from the winter feeding-grounds to their spring and summer ranges, flock after flock will be driven over the same driveways, along roads or narrow lanes. These driveways are usually overgrazed and at their best contain but little good feed. The first flocks going over eat out all the most palatable plants, leaving only the less desirable ones. The flocks that follow are forced to eat such plants and shrubs as death camas and rabbit brush, with disastrous results. Therefore, in moving sheep from one range to another, it is best not to allow one flock to follow another if the rabbit brush is the only feed left.

When sheep have been shipped long distances they are exceedingly hungry. Before starting to graze them on a strange range or on a range known to be infested with any poisonous plants, it is always much cheaper to fill them up on hay before moving them from the railroad point. Usually around loading corrals and shearing plants the range is overgrazed, a condition which favors the greatest losses from poisonous plants, especially rabbit brush.

LOCO

(*Aragallus* Spp. and *Astragalus* Spp.)

The almost universal name by which these plants are known on the western ranges is "Loco," from the Spanish word meaning crazy. They are therefore sometimes called crazy weed, from their effect on all classes of range animals.

Description of the Plant.

There are many different species of loco in Nevada, none of which cause serious losses. The locos belong to the pea family and have typical pea-blossom flowers borne in a crowded arrangement near the end of the flower stem. The flowers are of various shades of purple, yellow, white, or red. From them a pea-like pod is formed, often inflated or bladder-like in appearance, containing from two to many small seeds. The leaves have a very peculiar and characteristic appearance by which the plant may be readily distinguished on the range. They are made up of many small leaflets attached on each side of one leaf stem with an odd leaf always formed at the end, as shown in Figure 19.

Distribution and Habitat.

The locos are very widely distributed all over Nevada, being found on practically all grazing types such as the weed areas, sagebrush, open park, sand grass, white sage, and semidesert ranges. They are found at all elevations.

Animals Which Are Poisoned.

All classes of range animals are affected by these plants. However, sheep and horses are more likely to become locoed than are cattle.

There is only a small number of locoed animals in Nevada. The

main losses occur in the extreme southern part of the State, where but few cattle, sheep, and horses are ranged on account of the lack of water and feed.

Symptoms.

There are two ways in which the loco plant may affect range animals; (1) acute poisoning, killing them within a few days, and (2) slow poisoning, where the animals live for a considerable length of time, from six months to a year or more, during which time they show the same symptoms as in the acute form, only to a milder degree.

Figure 19. A loco plant, showing manner of growth and arrangement or leaflets on axis of leaf.

The most typical characteristic symptom of the locoed animal is the lack of muscular control when walking, the gait being like that of a drunken man. The animal's sight is impaired, and it cannot judge the size and distance of objects accurately. In serious cases total blindness occurs and the sense of hearing is frequently affected, often to such an extent that the animal is unable to determine the direction from which a sound comes. In cattle and horses the head is usually carried low, the coat becomes very rough, and the gait staggering

and slow. Frequently with sheep a general shedding of the wool takes place or it is shed only in patches. The back is quite frequently extremely arched, and there is trembling, especially of the legs and knees. It is almost impossible to keep a bunch of locoed sheep from

Figure 20. A loco plant, showing the hairy growth all over the plant. All locos producing this hairy growth may be looked upon with suspicion.

straying or to drive them in any definite direction. With many animals the sight becomes so badly affected that they cannot keep up with the flock, and they are often found dead in deep ravines, or drowned in

streams or water holes. As a result of feeding almost exclusively on loco the animal finally dies of exhaustion and starvation. In the later stages the locoed horse becomes very poor, his eyes are sunken, and he usually is abandoned by both man and beast, and will stand for days and even weeks upon a very small area of ground without water and with very little food until death from starvation relieves him.

Methods of Handling to Reduce Losses from Loco.

The loco weeds capable of causing the typical symptoms are highly unpalatable and are very rarely touched by any animal except those which are extremely hungry or which are grazing on a range where there is a distinct lack of more desirable plants. This is the case on all overgrazed ranges or where, due to climatic conditions, the loco weed is the predominating plant. Under these conditions the animals are forced to eat the loco. After having once developed an appetite for it however, they graze it in preference to all other range plants. When stock are grazing upon an area infested with loco a very close watch should be kept, and as soon as any of them commence to show signs of being locoed they should be immediately separated from the rest and placed in an inclosure and fattened. If this is not possible, they should be taken to a range free from loco.

If the animal has become rather poor, as is always the case after it has been eating the plant for some time, it should be given a very nutritious ration and for a few days 4 ounces of magnesium sulphate should be dissolved in the drinking water. In case of horses which are extremely nervous Fowler's solution should be given for from two weeks to a month in daily doses of 4 drams either in the drinking water or the grain.

Animals develop the loco habit primarily as a result of a lack of palatable nutritious range forage. After an animal has once acquired the taste for loco it must never again be turned on a range where the loco is found growing. In order to reduce the chances of sheep developing a taste for the plant, they should be grazed in open formation, which will allow natural freedom in the selection of their forage and they should be allowed to bed down wherever they are on the range at night. (See Figure 21.) When sheep are bedded for several nights on the same bed-ground they first graze out all of the most desirable plants, and such weeds as the locos are left until the last. If the use of the same bed-ground is continued after all the valuable plants have been removed, then these animals will be forced to eat the loco with a very good chance of developing the loco appetite. Further, when a sheep is hungry it is not particular about what it eats. Therefore, all flocks should be allowed to leave the bed-ground just as early as possible in the morning, for the longer they are kept from grazing the more hungry they become and the chances for their grazing the loco correspondingly increase. Ewes with lambs should at all times be allowed to graze openly and quietly because lambs are more likely to develop the loco habit than are the old ewes. If the lambs are separated for any length of time from their mothers, due to close herding, running and massing, they become very hungry with the increased possibility that while in this hungry condition they will eat the loco weed. Salt should always be supplied, so that the animals will not develop a perverted taste.

Figure 21. Sheep ready to bed down at evening on a new bed-ground. If the bed-ground is changed daily sheep are less liable to graze poisonous plants with fatal results.

Thus, in order to keep the number of locoed animals down to a minimum, they should be grazed openly, with little running or massing taking place, should be permitted if possible to choose their own bedground, should be supplied with a regular and liberal amount of salt, and allowed to graze during the early morning and evening hours, on range where there is an abundance and variety of good forage plants.

Figure 22. False hellebore, showing the manner of its growth and the shape of its leaves and flowers.

FALSE HELLEBORE

(*Veratrum* Spp.)

The common names by which this plant is known on the range are cow cabbage, wild Indian corn, Indian poke, poke root, bear corn, and swamp hellebore.

Description of the Plant.

A tall plant, growing from two to six feet high; thick, short root-stocks; leaves broad, clasping, prominently veined and plaited. The stems and flowers are covered with a fine growth of hairs; the flowers are a greenish-yellow or greenish-white in color.

Distribution and Habitat.

This plant is not widely nor abundantly distributed in Nevada. However, it is found quite frequently in certain mountain country where the soil is of a rich loamy nature and is supplied with a liberal amount of water. Thus it is found in swampy places, along streams and in wet meadows. Figure 22 shows the manner of its growth and the shape of its leaves and flowers.

Animals Which Are Poisoned.

In Nevada the only animals known to be poisoned by eating false hellebore are sheep. Cattle have been observed to eat the leaves with no ill effects after they have been frosted and turned reddish-brown in the fall of the year.

Many lambs have been poisoned because they ate the large buds and crowns just as they were commencing to grow in the spring. Many cases of poisoning have been observed on closely grazed ranges where the sheep filled up on the false hellebore almost exclusively, after which practically all the sheep in the flock became sick and several died.

Symptoms.

The first symptoms noted are extreme salivation accompanied by vomiting or attempts to vomit. With many animals there is a pronounced muscular weakness, muscular tremors, spasms, and general paralysis. The breathing in all animals which are too weak to be able to stand is shallow, the temperature is materially reduced, the skin is cold, the sight impaired, and death results from what may be called suffocation.

Methods of Handling to Reduce Losses from False Hellebore.

With the exception of lambs but very few sheep are fatally poisoned from eating the false hellebore. However, each season many sheep are made violently sick because they fill up exclusively on this plant. When it is eaten in moderate amounts it causes no ill effects, but when animals are allowed to fill completely on it, then poisoning takes place. In order to avoid this, care should be taken to allow the animals to eat it only moderately or else not at all.

Figure 23. To reduce losses from poisonous plants sheep should be allowed to graze openly and quietly, to give them the greatest possible chance to select their range feed.

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PLANTAS VENENOSAS A OVEJAS Y A GANADO EN LOS RANCHOS DE NEVADA

ESPUELA DE CABALLERO O CONSÓLIDA REAL. (LARKSPUR.)

Dos géneros de consólida real crecen en los ranchos de Nevada. Se conocen como consólida real alta y consólida real pequeña, nombres comunes basados en la altura de la planta.

Las consólidas real altas son plantas erguidas y ramificadas de dos a seis pies de altura, las raíces son grandes, hondas y bastante leñosas, con una o más copas de que se generan los tallos. La forma de la hoja se ve en figura 1. Las flores son de varios tintes de azul o púrpura y tienen una forma distintiva a causa de la estructura puntiaguda del sépalo superior indicado en figura 2.

La consólida real pequeña genera generalmente un solo tallo de 9 a 12 pulgadas de altura. Esta planta está indicada en placa I.

Plantas comunmente tomadas por consólida real.

Las dos plantas comunmente tomadas por consólida real son el geranio silvestre color de rosa (wild pink geranium) y el acónito (aconite).

En la primavera las hojas del geranio silvestre se asemejan mucho a la consólida real a causa de los dos pequeños y puntiagudos apéndices indicados en figura 2 que no se encuentran en el pecícolo de la consólida real. Si se aprieta la hoja del geranio el aroma característico del geranio resulta. La hoja de la consólida real no tiene este aroma. La hoja del geranio está generalmente cubierta de un crecimiento de vello pequeño, fino y pardusco, mientras que las hojas de la consólida real son cubiertas de una copa blanca de superficie borrable, muy parecida a la de ciruelas y de uvas.

El acónito se diferencia de la consólida real en que las hojas superiores del acónito son mucho más numerosas y casi no tienen vástagos. Las flores, en vez de ser puntiagudas como las de la consólida real, son cubiertas con una caperuceta como se ve en figura 2. Esto le da el nombre Inglés común de "monkshood."

Distribución y regiones donde crece la consólida real.

La consólida real se encuentra en casi cada rancho de la mitad septentrional de Nevada. Crece en lugares bien desaguados, húmedos y margosos; a lo largo de los lechos de riachuelos; en los campos abiertos de las montañas; y sombreado en parte por grupos de alisos y tiemblos.

La consólida real pequeña crece en suelos bien desaguados pero no demasiadamente húmedos y generalmente a plena luz del sol. Así, los cerros de las montañas y los ranchos de artemisia fronterizos son los dos lugares típicos donde la consólida real pequeña más abunda.

Animales que se envenenan por consólida real.

En las condiciones comunes de los ranchos sólo el ganado se envenena por la consólida real.

Partes venenosas de la planta.

Las plantas de consólida real alta que son la causa de la mayor parte

de las pérdidas son bien arraigadas, y cuando los animales se las apacentan, es casi una imposibilidad física que las raíces se desarraigen con la planta. Por consiguiente, se comen sólo las partes superiores y verdes.

Pruebas de alimentación indican que el veneno no se encuentra en las raíces pero en la parte superior de la planta. Las semillas forman la parte más venenosa, después las hojas, y ultimamente los tallos. Después de que la planta ha florecido el veneno desaparece de los tallos y de las hojas y se concentra en las semillas. De eso resulta que el ganado puede comer las hojas y los tallos de la consólida real después de que ha florecido y producido las semillas.

Cantidad de consólida real precisa para matar.

La consólida real es más venenosa durante su desarrollo temprano de Abril, Mayo y Junio. En cuanto que envejece se vuelve menos venenosa y para matar necesita mucho más de la planta que durante el primer período de desarrollo. Después de que la consólida real alta ha florecido, pierde su calidad venenosa y el ganado puede comerla sin gran peligro de hacerse daño. Pruebas de alimentación demuestran que necesita de consólida real 2½ a 3 por ciento del peso del animal para matarlo.

Síntomas de envenenamiento por consólida real.

En los terrenos de pasto la caída del animal es el primer síntoma que se observa y si el envenenamiento ha sido grave el animal no puede ponerse en pie otra vez y muere. Pero, la mayor parte de los animales, después de caer por primera vez, se ponen en pie y andan con las piernas traseras muy apartadas. Tambalean más o menos y hay poco o no movimiento en las articulaciones de las piernas. Cuando cae el animal, lo hace de una manera típica; en general las piernas delanteras se aflojan primeramente, entonces el animal se sostiene en que apoya la barba o el lado de la cabeza en el suelo. En los casos muy graves el animal se reposa tendido en el suelo y alza la cabeza de cuando en cuando, mientras que en los casos menos graves sostiene la cabeza erguida. Cuando está de pie se verifica un temblor por todo el cuerpo del animal, especialmente alrededor de la nariz y de la boca. Estas contracciones de los músculos se nota también alrededor de los hombros, de las caderas y de los costados. Con frecuencia hay un eructo de gas y un esfuerzo por el animal para vomitar. Hay un babear o babosear considerable. Casi invariablemente hay constipación.

Método curativo.

Después de que el animal ha caído no debe ser perturbado a menos que no yace en suelo barrancoso. En este caso hay que poner la cabeza más alto que el cuerpo para dejar respirar más facilmente al animal. El método de tratamiento común de sangrar el animal no debe ser empleado. Si el animal tienta de vomitar se puede concluir que ha tomado una dosis fatal y no se puede hacer nada para salvarlo. Generalmente hay buena esperanza de recuperación si se deja yacer el animal tan quieto que posible y se le da el tratamiento siguiente:

"Physostigmin salicylate" .....1 gramo,
"Pilocarpin hydrochlorid" .....2 gramos,
"Strychnine sulphate".....½ gramo.

Se administra esto de la misma manera que el vacunar contra morriña negra (blackleg). Se emplea una jeringa hipodérmica de 4 dracmas en la operación. Es preferible disolver la tableta en agua clara y limpia y, si es posible, hervida. No se repite la dosis.

Métodos de manejo de ganadería para reducir las pérdidas por consólida real.

Cuando se encuentra la consólida real en pedazos de terreno bien marcados, el método más sencillo para prevenir pérdidas es bien desherbar. Se deshierba la planta al menos 6 pulgadas debajo de la superficie del suelo. El precio medio para eso no debe superar 5 a 8 duros por acre.

En algunos ranchos es practicable primeramente dejar las ovejas pastar en los terrenos de consólida real hasta que la vitalidad de las plantas es muy reducida. Mientras tanto se reserva los terrenos no infestados para el ganado.

En todos los ranchos se debe siempre proveer sal liberalmente. Donde hay consólida real es preferible establecer terrenos de saladura a bastante distancia de los terrenos infestados por las plantas venenosas. Así el ganado no se congrega donde la consólida real abunda.

Es preciso nunca conducir ganado muy hambriento por terrenos de consólida real. Mientras que el estómago está vacío los animales comen muchas plantas que generalmente no tocan; y como la consólida real no es una planta sabrosa el riesgo de pérdidas es muy aumentado cuando los animales están hambrientos.

DEATH CAMAS. (ZYGADENUS.)

Los otros nombres comunes aplicados a "death camas" en los ranchos de Nevada son "poison wild onion," "poison sego," "poison camas," "mystery grass" y "lobelia." Sin embargo, "death camas" es el nombre más común y el que se debe emplear.

Descripción de la planta.

"Death camas" es una planta erguida que genera 5 a 7 hojas formadas como hierba gruesa. Crece de un bulbo de tongas puesto de 2½ a 6 pulgadas en el suelo. Este bulbo es de ½ a 1¼ pulgadas de espesor y es cubierto de envolturas finas parecidas a papel como se ve en figura 4. Las hojas son de 6 a 18 pulgadas de largo por un poco menos de media pulgada de ancho y tienen semejanza a hierba con lomo proyectante como una quilla de barco en el lado inferior. Tienen mucho más jugo y son más espesas que las hojas de hierba comunes. No hay tallo bien marcado y las hojas aparecen como si viniesen de la superficie del suelo. Las flores son de color amarillo-verdusco o blanco, de cuarta pulgada más o menos de ancho y producen un racimo de flores que es de 3 a 10 pulgadas de largo. En placa II se ve la apariencia típica de "death camas."

Plantas frecuentemente tomadas por "death camas."

Se confusa el "death camas" comunmente con la cebolla silvestre (wild onion). El bulbo y las hojas de "death camas" no tienen, sin embargo, el aroma de la cebolla silvestre y todas las flores de ésta crecen de una sola punta en la extremidad del pedúnculo, mientras que las flores de "death camas" se generan al lado del pedúnculo como se ve en figura 6.

Distribución y regiones donde crece el "death camas."

El "death camas" se encuentra en casi todos los ranchos de Nevada y los terrenos en que florece son invariablemente húmedos durante la primavera. Los lugares principales en que se lo encuentra son: (1) de artemisia, (2) de hierba, (3) prados y (4) terrenos típicos de mala hierba donde la vegetación consiste en plantas vistosas que producen flores. Se lo encuentra en los ranchos a mediados de Marzo y al fin de Junio ha muerto generalmente y el peligro de la planta ha desaparecido.

Animales que se envenenan.

Esta planta es venenosa a todas clases de ganado y especialmente a ovejas. Los caballos comen raramente bastante para causar muerte pero a veces hay pérdidas de vacuno cuando éste pasa en condición hambrienta por el rancho.

Partes venenosas de la planta.

Todas partes de la planta son venenosas pero comunmente los animales comen las flores y las hojas mientras que el bulbo está muy hondo en el suelo y rara vez se lo arrancan.

Cantidad necesaria para matar.

Un animal muy hambriento se envenena fácilmente. En el rancho una oveja de un peso de 100 libras más o menos tiene que comer de 1½ a 5 libras de la planta para envenenarse; para matar un cordero necesita proporcionalmente menos.

Síntomas de envenenamiento por "death camas."

Cuando una oveja se envenena por "death camas" el primer síntoma que se nota es que la andadura del animal es muy rígida, especialmente la de las piernas traseras. Cuando el animal cae lo hace comunmente con la cabeza antes, las piernas delanteras siendo más débiles que las traseras.

En casos muy graves el animal yace tendido en el suelo con respiración lenta y fatigosa. De repente respira muy rápidamente para un rato después de que vuelve a respirar lentamente. Con frecuencia hay un babosear de la boca con un molimiento de los dientes. El paladar es de color azulado. Casi invariablemente los animales envenenados vomitan. Se ha notado muchas veces que los animales tendidos en el suelo y respirando fatigosamente de repente dan fuertes puntapiés, tuercen el cuerpo y agitan la cabeza como si fuesen en agonía. Algunos mueren así pero la mayor parte entran en un estado de insensibilidad profunda de que no se puede despertarlos y así mueren.

Medios preventivos.

Las ovejas muestran gran cuidado en el escogimiento del forraje mientras que pastan tranquilamente en los ranchos. Pero mientras que se las conduce de un lugar a otro no pueden escoger el forraje y así comen todo lo que no es enteramente contra su gusto. Entonces, si hay "death camas" se lo comen en cantidades más grandes que de las que pueden descartar y de resultas mueren. Así, para evitar pérdidas es preciso tratar las ovejas de manera que nunca estén muy hambrientas. Si se las conduce de un terreno de pasto a otro hay que dejarlas tan tranquilo que posible durante una hora o dos por la

manaña antes de moverlas. Después de eso escogerán su forraje con cuidado de resultas que las pérdidas serán muy reducidas.

Para impedir pérdidas es muy preciso conducir las ovejas tan temprano que posible de los terrenos donde duermen porque más tiempo que tienen que quedarse en estes terrenos, más hambrientas estarán. Así tendrán menos cuidado en lo que comen en los terrenos de pasto.

El medio general de manejar ovejas, especialmente durante la primavera, consiste en establecer un campamento permanente a que se las conduce todas las noches hasta que todo el forraje en los terrenos alrededor del campamento ha desaparacido de un radio de 2 o 3 millas. De eso resulta que las ovejas comen todas las plantas, las venenosas antes y las no venenosas después de resultas que habrá pérdidas. En vez de este medio incorrecto de manejar, sería mejor dejar las ovejas acostarse por donde se hallen por ventura al anochecer. Así encontrarán forraje fresco al amenecer y los casos de envenenamiento serán muy reducidos.

Si una oveja no ha recibido sal durante una semana o diez días desarrolla un apetito anormal y come plantas que regularmente no tocaría. Así es preciso siempre proveer media onza de sal para cada oveja o una libra más o menos diariamente para cada treintena de animales.

ALTRAMUZ O LUPINO. (LUPINES.)

Los lupinos se conocen en Nevada bajo varios nombres comunes. Se los llama incorrectamente "blue bean," "wild bean," "wild alfalfa," y "blue pea."

Descripción.

El lupino apartenece a la familia de guisantes y es una planta erguida de 6 pulgadas a 3 pies de alto. La mayor parte de las especies de Nevada crecen de año en año de las mismas grandes raíces hondamente colocadas. Estas raíces generan varios tallos, las hojas de los cuales tienen pedúnculos largos. Hay 4 a 15 divisiones de hojas pequeñas, todas creciendo del ramal común como se ve en figura 8. Las flores son sostenidas en macollas largas y tienen una forma como las del guisante. Son de varios tintes de azul, blanco, rosado y amarillo. Las vainas contienen una o más semillas y generalmente son cubiertas de un crecimiento espeso de vello corto y fino. Este vello se encuentra en la superficie superior de las hojas, dando a la planta una apariencia pardusca. El lupino florece del principio de la primavera hasta el fin del otoño. Genera la mayor parte de las flores y de las vainas durante los meses de Julio y Agosto. En placa III se ve la apariencia típica del lupino.

Distribución y regiones donde crece el lupino.

El lupino es una de las plantas más copiosamente distribuidas en los ranchos de Nevada. Se lo encuentra en todas las elevaciones bajas y en todos los típos de suelo con excepción de los que son excesivamente húmedos o aridos o los que tienen demasiado álcali.

Animales que se envenenan.

En ciertas condiciones de los ranchos los lupinos pueden ser venenosos a todas clases de ganado. Las pérdidas principales resultan, sin embargo, cuando las ovejas comen el lupino después de que las semillas se han formado en las vainas. En el otoño cuando el otro

forraje escasea y lo que se queda es seco el lupino aun florece. Entonces las ovejas se lo comen y de resultas se envenenan. Cuando el lupino tiene semillas en las vainas es preciso no dejar las ovejas pastar en el terreno donde se lo encuentra a no ser que hay otras plantas que prefieran. Sin embargo, por todo el estado de Nevada hay un insecto pequeño que vive en las vainas del lupino y se alimenta de las semillas. Entonces las vainas aparecen como si contuviesen semillas, pero, examinandolas bien se ve que no las tienen y por eso no son venenosas.

Partes venenosas de la planta.

La mayor parte de las pérdidas son causadas por las vainas y por las semillas. En ciertas condiciones de los ranchos todavía no bien determinadas las hojas y las partes superiores de las plantas a veces causan pérdidas.

Cantidad necesaria para matar.

La cantidad que un animal tiene que comer para envenenarse es muy variable. Pruebas de alimentación muestran que para una oveja de cien libras de peso necesita ¼ a ½ libra de semillas sólo y aproximadamente 1½ libras de vainas y semillas juntas para matar.

Síntomas de envenenamiento por lupino.

El síntoma más común de envenenamiento por esta planta se ve en la manera de que respira el animal. En casos agudos o severos respira con gran dificultad. Durante estos períodos de respiración difícil el animal se tuerce violentemente y con gran excitación mental o corre en dirección indefinida, topezando con otros animales del rebaño o con cualquier obstáculo que encuentra en su paso, tal que morral, árboles o rocas. Acompañando la respiración difícil generalmente hay un babosear de la voca y el paladar es comunmente de color azul. Muchos animales mueren en un estado de espasmos violentes. Otros entran en un sueño profundo de que no se despiertan.

En casos menos agudos la respiración es fatigosa y las ovejas se quedan de pie o reposen en un sueño profundo. Otro síntoma típico consiste en que las orejas se inclinan y la oveja topeta otros animales o obstáculos con la cabeza. Después de que el animal ha pasado el período de respiración fatigosa se queda temblante por todo el cuerpo. Figuras 10, 11, 12, 13 muestran el ademán típico de ovejas envenenadas por lupino.

Método de manejar ovejas para evitar pérdidas.

Si se conduce ovejas que están en estado hambriento por terrenos donde florece el lupino, ellas comerán rápidamente las plantas, en particular las vainas y las semillas, en cantidades suficientes para matar. Por esta razón es preciso nunca conducir ovejas en estado hambriento por terrenos donde se sabe que florece cualquier planta venenosa. Cuando es necesario conducir ovejas una distancia considerable por terrenos infestados por lupino es muy importante dejarlas pastar antes tranquilamente durante las primeras horas del día. Después, en vez de moverlas rápidamente con perros, hay que dejarlas esparcirse tanto que posible y pasar así por los terrenos peligrosos.

CICUTA. (WATER HEMLOCK.)

Otros nombres comunes para esta planta son "cowbane," "chirivía silvestre" (wild parsnip), y "chirivía venenosa" (poison parsnip).

Descripción.

La cicuta es una planta que florece en pantanos. Es de 2 a 6 pies de altura. Se ramifica con lisos vástagos huecos de color verde creciendo de una macolla de raíces gruesas y ahusadas (figura 14) que tienen una serie de particiones cruzadas partiendo el interior de la raíz en cámaras pequeñas como se ve en placa IV. Esta placa muestra una cicuta típica. Las hojas son doblemente divididas y cada hojilla es estrecha y finamente dentada por lo largo del borde. Genera flores blanco-verdosas en macollas compactas en las extremidades de las ramas.

Plantas comunmente tomadas por cicuta.

Cuando se corta la raíz de la cicuta longitudinalmente se ve las particiones cruzadas y las cámaras pequeñas ya mencionadas. Sin embargo, hay otras plantas que tienen la misma estructura de la raíz, notablemente el anís dulce (sweet anis) y la berraza (water parsnip). El anís dulce no florece en suelos muy húmedos pero se lo encuentra a lo largo de los lechos de riachuelos de la montaña y en lugares tranquilos y bien sombreados. Las hojillas del anís son mucho más anchas que las de la cicuta. El anís florece durante la primera parte del verano mientras que la cicuta no florece antes de pleno verano. El anís es muy sabroso y no envenena el ganado.

La berraza crece en lugares húmedos como la cicuta. Pero, se puede facilmente distinguir ésta de aquélla en que las hojas de la berraza no se ramifican mientras que las de la cicuta son divididas o ramificadas como se ve en figura 15.

Distribución y terrenos donde florece la cicuta.

La cicuta es una planta que florece en lugares muy húmedos como por lo largo de las orillas de zanjas de regadura y de riachuelos, en pantanos de espadaña (tule) y en prados silvestres de heno. No tiene gran esparcimiento. No se la encuentra nunca afuera de terrenos muy húmedos.

Animales que se envenenan.

La planta es muy venenosa para todas clases de ganado. En Nevada la mayor parte de las pérdidas consiste en ganado vacuno. Raramente hay pérdidas de caballos ú ovejas.

Partes venenosas de la planta.

Todas partes de la planta son venenosas pero las raíces lo son mucho más que las verdes partes superiores.

Cantidad de raíz de cicuta necesaria para matar.

Necesita sólo una porción pequeña de la raíz de la planta para matar. La mayor parte de los casos graves relatados eran causadas por una porción de la raíz de grandor de un huevo de gallina o menos.

Síntomas de envenenamiento por cicuta.

Los primeros síntomas son: (1) contracción nerviosa de los músculos de la boca y de las orejas; (2) generalmente náusea y vómito en los casos de ganado vacuno y de ovejas; (3) un babosear cuantiosa de la boca y un temblor por todo el cuerpo; y (4) espasmos violentos con un atiesar de las piernas y un encorvar hacia atrás de la cabeza y del

cuello. Los intervalos entre los espasmos disminuyen hasta que el animal se queda insensible y al fin muere.

Remedios.

No se ha encontrado todavía un remedio satisfactorio y eficaz contra envenenamiento por cicuta. Es preciso perturbar el animal tan poco que posible para aumentar la suerte de su recuperación.

Métodos de manejo para disminuir pérdidas por cicuta.

La cicuta tiene tan poca distribución y abundancia que es muy fácil exterminarla en los ranchos donde causa pérdidas en que se deshierba la planta y las raíces y las quema o las entierra hondamente. En los terrenos de pasto es muy fácil reunir las ovejas afuera de los lugares donde crece la cicuta cuando el pastor conoce la apariencia de la planta.

WESTERN GOLDENROD. (SOLIDAGO.)

Hay dos especies de "goldenrod" que causan pérdidas en Nevada. Todos crecen en terrenos de heno silvestre, en dehesas permanentes y en campos abiertos y bien desaguados de las montañas.

Descripción.

Los "goldenrods" que causan pérdidas son de un pie o más de altura y tienen hojas indivisas. Alrededor de la base de la planta las hojas se adelgazan hacia el tallo. Las hojas que se generan en el tallo son angostas, dos a cuatro veces más largo que ancho y redondeadas más o menos en perfil. Las hojas que se generan cerca de o juntas a las flores son pequeñas, angostas y llanas. Les flores son amarillas y crecen en macollas espesas al cabo de un vástago ramificado. Placa V muestra la apariencia típica del "goldenrod." Es esta especie de la planta que ha causado muchas pérdidas en Nevada.

Distribución y terrenos donde crece el "goldenrod."

En Nevada el "goldenrod" crece en terrenos de heno nativos, en terrenos de pasto bien desaguados y en campos abiertos y prados de las montañas. No se lo encuentra en terrenos áridos de artemisia o por donde crecen el herbajo y la hierba seca.

Animales que se envenenan.

Hasta ahora las pérdidas notadas consisten sólo en ovejas que habían comido esta planta en terrenos de pasto o mezclada con heno.

Partes venenosas de la planta.

Los animales comen sólo la parte superior de la planta, especialmente las hojas, las flores y los tallos tiernos.

Cantidad de "goldenrod" necesaria para matar.

Algunas ovejas se han envenenado en que habían comido 1.1 libras de la planta verde. Otras pérdidas han resultado de que los animales habían pastado en la planta que era mezclada con heno o la habían comido en terrenos de pasto donde había una abundancia de otras plantas. Eso prueba que la planta es muy venenosa y que sólo una cantidad pequeña es necesaria para matar.

Síntomas.

Los síntomas primeros consisten en salivación o babosear acompañado con un movimiento continuo de las mandíbulas y de los labios. Hay también un movimiento continuo de las orejas y de la cabeza con una contracción recurrente y violenta de los músculos del cuerpo. Cuando ocurren estas contracciones parece que el animal tentase de sacudir alguna cosa de su vellón. Mientras que el animal se sacude así hay un arqueo fuerte del dorso. Las piernas son generalmente muy juntadas como que fuesen recogidas bajo del cuerpo. Un ruido repentino causará el sacudir del vellon ya describido. Las contracciones de los músculos principian con la cara y con la cabeza, entonces pasan por el cuello y por el dorso y finalmente afectan las piernas. Después de ser envenenados, muchos animales dejan el rebaño sin ningún motivo y se ponen en marcha en una condición aturdida, plantando los pies delanteras alto y con la cabeza erguida. Se quedan en esta posición durante un minuto o más. Entonces hay un estremecimiento de los músculos de las piernas, del cuello y del dorso con una flaqueza repentina y una inconstancia de andadura. La oveja cae generalmente después y entra en espasmos. Las pupilas se dilatan y los sentidos de vista y de dirección son completamente trastornados. Tan pronto que cesan los espasmos hay un mascar de las mandíbulas, un babosear, un sacudir continuo de la cabeza y un temblor del cuello. Parece que todos los animales envenenados tuvuisen un deseo indomable de asir un objeto, tal que una piedra o un palito y masticarlo durante horas enteras.

Métodos de manejo para reducir pérdidas por "goldenrod."

Pérdidas enormes han resultado de que se ha dado a las ovejas del "goldenrod" mezclado con heno. Si el heno es destinado para ovejas es preciso determinar los terrenos donde crece el "goldenrod" y el heno de estes terrenos debe ser amontado en lugares particulares y dado al ganado o a los caballos, animales que hasta ahora parecen ser inmunes de los efectos venenosos de esta planta. Cuando se pasta las ovejas en terrenos donde crece el "goldenrod" hay que dejarlas la más grande libertad posible en su selección del forraje. Para mantener un apetito normal hay que darlas sal regularmente y en abundancia. Frecuentemente el "goldenrod" crece espesamente en pedazos de terreno particulares de resultas que es muy facil pastar las ovejas afuera de estos terrenos. Para hacer eso hay que conocer bien la planta y distinguirla de las otras. Placa V muestra bien la apariencia de esta planta. Cuando se seca el "goldenrod" mezclado con heno las flores amarillas generalmente se quedan en la planta de resultas que es muy facil encontrarlas si acaso se sospecha que la causa de pérdidas esté en el heno.

RABBIT BRUSH. (TETRADYMIA.)

Esta planta es venenosa durante ciertas sazones del año y en ciertas condiciones. Recientemente ha causado la pérdida de unas millares de ovejas en la parte occidental de Nevada.

Descripción.

El "rabbit brush" es un arbusto rígido de 1 a 4 pies de altura. Tiene ramos delgados y desplegados. Estos ramos son blanqueados por vellos lanosos y esterados. Las hojas son lisas y verdes. Las hojas sazonadas

son delgadas y rematadas en punta mientras que las verdes son gruesas y sin punta. Las flores son amarillas y son sostenidas en macollas. Placa VI muestra un ramo típico de este arbusto y en figura 17 se ve la manera típica de su crecimiento y de su ramificación. El "rabbit brush" espinoso se encuentra frecuentemente creciento junto con el "rabbit brush" antedicho. Es también un arbusto y de 3 a 4 pies de altura. Tiene los ramos muy separados. Estos son cubiertos por un vello espeso y blanqueado. Tienen espinas derechas o curvas en vez de las hojas principales. Según lo que se ya sabe el "rabbit brush" espinoso no es venenoso.

Distribución y terrenos donde crece el "rabbit brush."

Se encuentra el "rabbit brush" en terrenos áridos de artemisia. La vegetación característica con que crece consiste en artemisia, "bud sage," "white sage," "shad scale" y las salivas verdes (green sages). Frecuentemente se encuentra el "rabbit brush" donde no hay otra vegetación. So lo encuentra nunca en terrenos montañosos.

Animales que se envenenan.

Es probable que sólo las ovejas se envenenan.

Partes venenosas de la planta.

Durante la primavera este arbusto produce pimpollos y hojas en que pastan las ovejas. Estas partes de la planta han sido la causa de las pérdidas.

Cantidad de "rabbit brush" necesaria para matar.

Según lo que se sabe hasta ahora, una oveja para envenenarse tiene que pastar exclusivamente en esta planta hasta que el estómago está casi lleno. Las hojas verdes y tiernas y los pimpollos contienen dos por ciento más o menos de potasa, un veneno fuerte. Este veneno puede ser la causa de las pérdidas de ovejas. La mayor parte de las pérdidas en Nevada consistía en animales muy hambrientos o tales que eran mantenidos en haciendas durante todo el invierno y después eran conducidos por terrenos donde florecía el "rabbit brush."

Síntomas.

Después de que una oveja se ha llenado el estómago con vástagos de "rabbit brush" se pone muy torpe. Vacila y a veces cae de repente en condicion insensible con la cabeza torcida a un lado. Entonces sigue un espasmo de los músculos. Los ojos se comban y saltan a la vista. La respiración es muy ligera. La nariz y la cara se arrugan como si la nariz estuviera obstruida por cualquier obstáculo. Los animales que están tendidos en el suelo casi siempre trituran los dientes después de que se hinchan. Hay especialmente un hinchar de la cabeza y de las orejas en los casos de muchos de los animales envenenados. Un moco rayado por sangre viene de la nariz. El animal muere generalmente en un rato de cinco minutos a una hora después de caer.

Remedios.

Cuando una oveja está envenenada por "rabbit brush" hay poco que se puede hacer para curarla. Generalmente cuando hay casos de este envenamiento en un rebaño es probable que muchos animales están tendidos en el suelo al mismo tiempo así que un tratamiento particular es imposible.

Métodos de manejo para disminuir pérdidas por "rabbit brush."

Es posible evitar pérdidas casi enteramente en que se pasta los animales con cuidado. La cosa más importante es el saber que las ovejas comen esta hierba cuando están muy hambrientas o cuando hay carestía de otro forraje. El pastor debe aprender como se distingue este arbusto a primera vista. Cuando ve que las ovejas pastan casi exclusivamente en las partes tiernas y verdes de esta planta debe inmediatamente conducirlas a terrenos donde no hay "rabbit brush." Es especialmente preciso saber esto cuando se conduce los animales de un terreno a otro, cuando están en terrenos de pasto a lo largo de ferrocarriles, cuando están en los corrales de esquilar y después de que se los ha transportado una gran distancia de resultas que están muy hambrientos.

LOCO. LOCO WEED. (ASTRAGALLUS O ARAGALLUS.)

El nombre común de esta planta viene de que los animales envenenados parecen como si fuesen en un estado de locura.

Descripción.

En Nevada hay muchas especies diferentes de "loco," nigunas de las cuales causan grandes pérdidas. Los "locos" apartenecen a la familia de guisantes y tienen la flor típica del guisante. Esta flor se genera en colocación apretada cerca de la extremidad del pedúnculo y tiene varios tintes de púrpura, de amarillo, de blanco y de rojo. La vaina es generalmente hinchada en apariencia como la del guisante y contiene dos o más semillas pequeñas. Las hojas son de una estructura particular de resultas que se puede facilmente distinguir el "loco" de las otras plantas en los terrenos de pasto. Estas hojas son compuestas de muchas hojuelas que se adhieren a los dos lados del pecícolo. Hay siempre una hojuela sobrante en la extremidad del pecícolo come se ve en figura 19.

Distribución y terrenos donde crece el "loco."

Los "locos" son muy distribuidos por todo el estado de Nevada. Se los encuentra en todos los terrenos de pasto con excepción de los prados húmedos, los terrenos bien arboleados y los terrenos llenos de álcali.

Animales que se envenenan.

Todas clases de animales se envenenan por "loco" pero las ovejas y los caballos son mucho más susceptibles que el ganado vacuno. Las pérdidas en Nevada no son muy importantes y ocurren principalmente en la parte meridional del estado donde hay pocos animales en los ranchos a causa de la carencia de agua y de forraje.

Síntomas.

El "loco" afecta los animales de dos maneras: (1) por envenenamiento agudo después de que los animales mueren en pocos días y (2) por envenenamiento crónico después de que viven de seis meses a un año o más.

El síntoma más caracteristico de envenenamiento por "loco" es la falta de dominio exacto sobre los músculos de resultas que la andadura del animal es muy semejante a la de un borracho. El sentido de la vista se afecta y el animal no puede juzgar correctamente el tamaño y la distancia de objetos. En los casos más graves se queda enteramente ciego y el oído se afecta frecuentemente de un modo que el animal no

puede determinar de que dirección viene un sonido. El ganado vacuno y los caballos llevan la cabeza bajo generalmente, el pelo deviene muy áspero y la andadura es muy vacilante y lenta. En el caso de ovejas con frecuencia hay un arrojar de la lana general o en pedazos. El dorso es muy arqueado y especialmente hay un estremecimiento de las piernas y de las rodillas. Es casi imposible retener las ovejas envenenadas en rebaños o conducirlas en una dirección determinada. Muchas veces el sentido de la vista se afecta tanto que no pueden ir adelante con el rebaño de resultas que se las encuentra después muertas por los barrancos o ahogados en los riachuelos o en los abrevaderos.

Un resultado del pastar casi exclusivamente en "loco" es que al fin el animal muere de debilitación y de hambre. Un animal envenenado así se pone al fin muy abatido, los ojos son húmedos y generalmente se queda abandonado por hombres y por bestias. Se queda durante días y aun semanas en un terreno pequeño sin agua y con poco forraje hasta que la muerte lo relieve.

Métodos de manejo para reducir pérdidas por "loco."

Los "locos" capables de causar los síntomas caracteristicos son muy ingustables y los animales los tocan raramente excepto cuando están muy hambrientos o están en terrenos de pasto bien apacentados o por donde el "loco" es la planta predominante. En estas condiciones los animales comen el "loco" por fuerza. Cuando han desenvolvido un apetito para esta planta se la comen con preferencia a todo el otro forraje.

Cuando los animales pastan en terrenos infestados por "loco" hay que guardarlos bien y tan pronto que principian a dar signos de ser envenenados es preciso separar los que son así envenenados de los otros animales del rebaño, ponerlos en vallados y engordarlos. Si eso no es posible es preciso conducirlos a terrenos de pasto donde no hay "loco." Los animales desarrollan el hábito de comer "loco" cuando hay carestía de forraje sabroso y nutritivo. Después de que un animal ha adquirido el gusto para "loco" no se debe nunca dejarlo correr por terrenos donde crece esta planta. Para evitar que las ovejas desarrollen el gusto para "loco" es preciso pastarlas en formación abierta y dejarlas gran libertad en su escogimiento del forraje. También es importante dejarlas pasar la noche por donde se encuentran al anochecer y no conducirlas a un campamento particular.

Cuando las ovejas pasan algunas noches en el mismo terreno es natural que pastan antes en las plantas más sabrosas y dejan las otras, tales que los "locos" hasta al fin. Si continuan a pastar en el mismo terreno hasta que no hay más plantas sabrosas el resultado es que entonces comen el "loco" por fuerza y así desarrollan el gusto para esta planta venenosa. Además de eso, cuando el animal está muy hambriento no es muy escrupulosa en el escogimiento de su forraje. Por eso es importante conducir los rebaños de los terrenos donde duermen tan temprano que posible porque más tiempo que se quedan en estos terrenos más hambre tendrán de resultas que la probabilidad de que comerán del "loco" será muy aumentada. Especialmente hay que pastar los corderos con cuidado porque desarrollan el gusto para "loco" más facilmente que los animales más viejos. Si se separa los corderos de sus madres para algun rato durante que se pasta los rebaños apretadamente el resultado es que los corderos devienen muy hambrientos y en esta condición la probibilidad que comerán el "loco"

es muy aumentada. Es importante siempre proveer bastante sal para que no desarrollen apetitos perversos.

ELÉBORO SEUDO. (FALSE HELLEBORE.)

Los nombres comunes en los ranchos para esta planta son: "cow cabbage," "wild Indian corn," "Indian poke," "hierba fétida" (skunk cabbage), "bear corn" y "swamp hellebore."

Descripción.

Esta planta es de 2 a 6 pies de altura y tiene raíces gruesas y cortas. Las hojas son anchas, abrazadas, veteadas y alechugadas. Las flores y los tallos son cubiertos de un vello fino. Las flores son de color amarillo-verdusco o blanco-verdusco y amarillo. Figura 22 muestra el eléboro seudo como florece en los ranchos.

Distribución y terrenos donde crece el eléboro seudo.

Esta planta no es muy distribuida en Nevada. Sin embargo se la encuentra frecuentemente en ciertos terrenos montañosos donde el suelo es fértil y margoso y donde hay gran cantidad de agua.

Animales que se envenenan.

De lo que se sabe hasta ahora sólo las ovejas se envenenan. Se ha notado algunos casos de envenenamiento en ranchos bien pastados donde las ovejas habían comido vorazmente el eléboro seudo de resultas que todas se envenenieron y algunas murieron.

Síntomas de envenenamiento por eléboro seudo.

El primer síntoma notado consiste en una salivación copiosa acompañada por un vomitar o un tentar de hacerlo. En los casos de muchos animales hay una gran flaqueza de los músculos, estremecimientos, espasmos y una parálisis general. En los casos de todas las ovejas envenenadas y demasiado débiles para quedarse en pie la respiración es floja, la temperatura muy reducida, la piel fría y la vista afectada. La muerte por sofocación resulta finalmente.

Métodos de manejo para reducir pérdidas por eléboro seudo.

Las pérdidas consisten generalmente en corderos. Para evitar pérdidas por eléboro seudo hay que dejar las ovejas comerlo sólo moderadamente o de ningún modo. Como la plante crece en áreas bien definidas es enteramente practicable evitar que los animales pasten en ella exclusivamente y así no comerán bastante para hacerse daño.

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AGRICULTURAL EXPERIMENT STATION
THE UNIVERSITY OF NEVADA

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DON'T FEED FOX-TAIL HAY TO LAMBING EWES!

By
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Of the Department of Range Management, Agricultural Experiment Station

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Owing to the exhausted condition of many of the winter sheep-ranges in Nevada, and because of the rising value of wool and mutton, it is becoming customary in many parts of the State to bring ewes in to the valley ranches and feed them on hay during the lambing season and for a few weeks later.

A number of the larger sheep-owners and livestock companies have recently made heavy investments in sheds and corrals for lambing under shelter in order to increase the percentage of lambs saved and to put both lambs and ewes upon spring range in the best possible condition.

The feeding of hay to lambing bands has not proven successful, owing to the fact that on hay alone the ewes give very little milk. A study of the problems connected with the early spring feeding of lambing bands was begun in 1919 by the Nevada Agricultural Experiment Station as Project 24, Hatch Fund. In connection with this project an examination of various kinds of local hay fed in the spring of 1919 showed that some of the hay produced in western Nevada not only lacks feeding value, but may prove dangerous to the life of ewes and lambs; and, under certain conditions, may cause heavy losses. These studies were conducted by C. E. Fleming, Head of the Department of Range Management in the Nevada Agricultural Experiment Station; and, because of their importance, are presented in this bulletin.

ACKNOWLEDGMENTS

The Experiment Station takes this means of expressing its sincere thanks to Dr. Robert Dill, Inspector in Charge, State Board of Sheep Commissioners, for assistance in the study of squirrel-tail injuries to sheep. Dr. Dill visited the bands where deaths were occurring, and showed that the losses had been unnecessarily increased by the manner in which the hay was fed.

Dr. Edward Records, Head of the State Veterinary Control Service, and Head of the Department of Veterinary Science in the Experiment Station, made post-mortem examinations and dissections in a number of cases. He also visited corrals where the sheep were dying, and examined both dead and living sheep. He was assisted by Dr. L. H. Wright of the Experiment Station, and Dr. R. C. Louck, Pathologist, State Veterinary Control Service.

Drs. Records, Wright, and Louck felt that it would be unwise to conclude that all the deaths among the sheep fed on squirrel-tail hay were due to this noxious grass, because losses in lambing bands occur

normally from a variety of other causes, some of which were observed in the cases studied.

On the whole, however, there seemed to be abundant evidence that a very large part of the deaths, amounting in one band to several hundred ewes and lambs, were caused by this grass. In the fatal cases the grass blinded the ewes or made their mouths so sore that they either died of starvation or else fell easy victims to common diseases.

S. B. DOTEN,
Director Nevada Agricultural Experiment Station.

DON'T FEED FOX-TAIL HAY TO LAMBING EWES!

This bulletin presents the results of observations upon the injurious effects of feeding ewes during the lambing season on hay containing quantities of squirrel-tail grass (*Hordeum jubatum,* squirrel-tail, tickle grass, fox-tail grass). Humane considerations, as well as self-interest, should forbid the use of hay in which it makes up any large part of the bulk. This grass is worth little for grazing; and when put up in hay it is dangerous. Fields and meadows on which it grows would be improved by its destruction. No other weed concerns the users and producers of hay for sheep feeding so much as squirrel-tail grass. It is dangerous as soon as it heads; when dried and fed in considerable quantities it becomes obnoxious and destructive.

Common Names:

This grass is usually spoken of by any one of four common names: squirrel-tail grass, fox-tail grass, tickle grass, and wild barley. The name squirrel-tail grass is probably more generally used than any of the other three. However, in the Rocky Mountain region it is very frequently called either fox-tail grass or tickle grass. These names have come into general use because (1) "squirrel-tail," "fox-tail" and "wild barley" clearly describe the appearance of the seed head, and (2) "tickle grass" describes the irritating sensation produced when the beards rub against the skin. It is because of these awns (beards) that this grass may fairly be called one of our worst pests, not only because they are directly or indirectly responsible for loss of condition and death of sheep, but also because of the pain and suffering produced when fed in hay.

Description:

Squirrel-tail grass is a perennial, coming up each year from the same mass of roots; thus it is not dependent upon its yearly crop of seeds for its perpetuation. It develops a strong fibrous mat of little roots, from which arises a single compact bunch of leaves and stems. The size of the bunch depends on the age of the grass, for it becomes constantly larger as the plant grows older until it is from 6 to 10 inches across. Squirrel-tail grass is a coarse ragged grass from 6 to 24 inches high, according to soil and moisture conditions. It bears numerous slender flat leaves which are much paler when young than the leaves of the common blue-grass. The seeds are borne in a dense spike (seed head) from 2 to 4 inches long, purplish in color at first, or pale green, but later turning to a greenish straw color. Figure 1 shows the general shape of the seed head, which may be described as consisting of a large number of one-seeded spikelets which, when mature, break up into joints consisting of one perfect flower or seed and two rudimentary spikelets all bearing awns (beards), a total of seven in number.

The number of seeds in a head varies from 30 to 60, with an average of approximately 40 seeds to the head. A plant four inches across the crown will produce about fifty heads to the plant with a total of approximately 2,000 seeds or 14,000 awns per plant. At this rate an

Figure 1. "Squirrel-tail" with Bearded (Awned) Seeds.

acre of ground with one plant growing on every square foot would produce nearly 90,000,000 seeds and more than 600,000,000 awns. With the production of so many millions of seeds and barbed awns capable of attaching themselves to the skin and wool of sheep, the plant is admirably adapted for rapid and widespread distribution.

Distribution:

This grass is now widely and abundantly distributed across North America. Formerly it was confined almost entirely to the Rocky Mountain region, where it grows around the borders of ponds, in swampy alkaline flats, along streams and irrigation ditches, and in meadows and fields wet from overirrigation or seepage.

Today it is widely and abundantly distributed in Nevada. In many places it is becoming a serious menace on land which is used for the production of hay. On every piece of hay land where it has become established it is a troublesome weed which materially reduces the feeding value and the sale price of the hay.

Wind and irrigation water are the two chief means of distribution, although undoubtedly it is often carried long distances in the wool of sheep. It grows not only at the lower altitudes, but often in the mountains as high as 8,000 or 9,000 feet.

Means of Control:

Because of the fact that squirrel-tail grass is not an annual, it cannot be completely controlled or eradicated by early cutting or frequent clipping, the purpose of which would be to prevent it from going to seed. There seems to be a widespread belief that this grass depends for its perpetuation upon its annual crop of seeds. This is a mistake, for it is a perennial, living from year to year upon the same root stem.

Carried everywhere by wind, water, and grazing animals, it spreads to all hay lands and becomes established if conditions are favorable, growing best in low and wet spots. Often in the spring and early summer the better native and cultivated grasses are partially killed out by an excess of water and are permanently replaced by squirrel-tail. This is apt to occur if water is allowed to stand on hay fields during winter and spring, or if the fields are constantly overirrigated.

On a piece of land where squirrel-tail has become abundant, complete success has been obtained in getting rid of it by plowing the ground deeply and seeding down to a crop of oats and peas, after which the ground was replowed and sown to alfalfa. When it becomes established in considerable quantity in any field, it is quite a sure indication that the better forage plants have been run out by too much water. It is then best and safest to break up the land, level it, and plant to a cultivated crop for a year or so. If this is not practicable, the land should be plowed deeply and resown; no more water should then be applied than the crop needs for good growth.

This grass commences to grow very early in the spring and is usually from two weeks to a month ahead of the other forage plants with which it is associated. Consequently it is ready to head out much earlier than the others, or about June 1 at Reno. Thus, when the hay crop is ready to cut, the "squirrel-tails" have already been produced; and the hay cannot be harvested without containing masses of the injurious awns. A practical means of preventing losses from squirrel-

tail grass on hay lands is to graze with sheep early in the spring when the grass is high enough to be tempting and palatable. This early and severe grazing has two distinct beneficial results: (1) it reduces the vitality of the squirrel-tail grass, and (2) it gives the other grasses an even chance to grow; for by the time the sheep are removed the squirrel-tail grass is closely cropped to the ground. The hay is harvested just at the time the heads of the squirrel-tail grass are beginning to appear. The above method of decreasing the injurious effects of squirrel-tail grass in infested fields has been tried out and practised

Figure 2. Squirrel-tail Grass in Hay.

by Walts Brothers on their ranch near Reno, and the hay has been fed without harmful effects.

Cause of Injury when Fed to Live Stock:

Figure 2 shows a small bunch of hay containing the heads of squirrel-tail grass.

Part of a single awn (beard) of this grass is shown in Figure 4. The awn bristles with small barbs with reinforced bases and extremely sharp cutting points. These barbs all point backward, so that when the awns become attached or lodged in the tissues or skin they continue to travel in one direction only, the pointed barbs preventing them from loosening up and coming out.

Mechanical Injuries Caused:

The awns most often infest the delicate tissues in the region of the eye, the membranes of the mouth, the sides of the jaw, or the wool

Figure 3. Bunch of Squirrel-Tail Grass.
(Fox-tail, Tickle grass, *Hordeum jubatum.*)

of the head, neck, and back. As soon as they become lodged, they begin to work into the flesh, causing injuries which affect the condition of the animal and frequently lead to very serious consequences or death.

In the examination of heads of sheep the following types of injury were observed: (1) Some awns found in the ears, where they caused abscesses, due to mechanical injury and subsequent infection by bacteria; or (2) in the mucous membranes of the upper and lower eyelids, causing inflammation with a discharge of a yellowish-white opaque creamy pus. (3) They were commonly found between the eyeball and the tissues of the orbit, causing semi- or total blindness. (4) Many awns had penetrated the skin of the head between the nose and the forehead or on the cheek and around the eye, causing the wool and

Figure 4. Part of Single Awn (Beard). Magnified (X100.)

hair to slough off with the formation of pustules, or small abscesses. (5) They had become imbedded in the lips, causing redness and swelling, with a formation of small pimple-like elevations filled with pus. (6) Awns were common on all surfaces of the tongue; and (7) in the openings of the glands secreting into the mouth. (8) Others had penetrated into the nasal passages, causing extreme irritation. (9) In nearly all heads examined, masses of awns were embedded in the gums beside the molars of both upper and lower jaws. (10) They had worked in around the incisors and caused them to loosen in their sockets and fall out. The gums had shrunken away from the teeth and in many cases there was ulceration and decay. In other instances they were embedded in the palate. (11) Many were found in the soft tissues under the tongue.

The following examinations were made of heads selected at random on March 14, 1919, from a pile of over 300 carcasses of ewes that had been feeding on hay containing a high percentage of squirrel-tail grass. The hay consisted mainly of timothy and meadow grasses and a small amount of alfalfa:

Case No. 1: Awns were found in the lower molars, the front teeth had dropped out, and awns had penetrated the cavities in which the teeth had been. Awns were also found around the eyes and in the sublachrymal pits.

Case No. 2: Awns were found alongside and between the teeth of the upper and lower molars and in the sublachrymal pits.

Case No. 3: A few awns were found lodged in the outer opening of the ear (external auditory meatus).

Case No. 4: Awns were found alongside and between the front teeth and lower and upper molars. The lower jaw was ulcerated on both sides, due to the awns penetrating down to the sockets of the molars.

Case No. 5: Awns were found between and alongside all of the front teeth and also the upper molars. The lower jaw was slightly ulcerated in the region of the molars. Awns were present under the tongue, in one eye and in the sublachrymal pits.

Case No. 6: Awns were found around the front teeth and had penetrated the gums of the lower molars and the membranes under the tongue. A bunch of awns about three inches up in the nasal cavity was also found.

Case No. 7: Awns had penetrated the gums of the front teeth and also the lower molars, and the membranes under the tongue. Several awns had worked into the inner surface of the cheek. The sublachrymal pits also contained many awns.

Case No. 8: Both eyes and both sublachrymal pits were invaded by awns and they were also present around the

front teeth and around and between the upper and lower molars. Some had penetrated the palate and large numbers were found in the tissues under the tongue. A few were present in the nasal cavity.

Figure 5. Eye Blinded by Awns. Upper Lip Cut Away to Show Mass of Awns Between Teeth and Lip.

Figure 6. Awns Embedded in the Angle of the Lower Jaw: Pus Exuding.

Case No. 9: Awns were found around the front teeth and around and between both the upper and lower molars. Both eyes were affected.

Case No. 10: Both eyes were badly injured by awns and they were also present in the sublachrymal pit, around the front teeth, around and between the upper and lower molars and in the tissues under the tongue.

Case No. 11: Awns were found around the front teeth, between and around the upper and lower molars, in the gums immediately back of the front teeth, in both eyes, and in both sublachrymal pits.

Case No. 12: Awns were found in the gums of the front teeth, the upper and lower molars, in the upper and lower lips, in the palate and in the back part of the nasal passage. The upper jawbone was ulcerated and the gums were badly affected. Awns were also present in both eyes, under the tongue, in the upper surface of the tongue, and in both sublachrymal pits.

Case No. 13: The molars of both jaws were infested with awns, and the lower jaw was ulcerated on one side. The upper lip, both eyes, and both sublachrymal pits were badly affected.

Case No. 14: Awns had penetrated the gums of the front teeth. Others were found in the gums of the upper and lower molars, in the outer opening of the ear, in both eyes, in both sublachrymal pits. Both the upper and lower jaws were ulcerated.

Case No. 15: The front teeth had become loosened and had fallen out, the gums were badly affected, the gums and sockets of both upper and lower molars were freely penetrated with awns; many awns had pierced the soft palate and become lodged. Awns had penetrated the Eustachian tubes, the upper lip, the nasal passages, both eyes, both ears and both sublachrymal pits.

Case No. 16: The sockets of the front teeth, the upper and lower molars, and the lips were full of awns. Many awns were found lodged on both sides of the tongue and under it, in both eyes, both sublachrymal pits and the ears.

Case No. 17: The front teeth had become loosened and had fallen out; the sockets of the upper and lower molars were freely penetrated with awns. One upper molar had become loosened, and many awns and other material had become lodged in the gums to an extent which had made feeding extremely difficult. Both eyes were also badly affected.

Case No. 18: Awns had penetrated and had become lodged in the gums of the front teeth, around both the upper and lower molars, in one eye and in both sublachrymal pits.

Case No. 19: The gums and sockets of the front teeth and the upper and lower molars had become freely penetrated with awns, especially one of the lower molars. Awns were also found lodged under the tongue, in the lower lip, in both eyes, and in both sublachrymal pits.

Case No. 20: The gums of the front teeth and the upper and lower molars had many awns lodged in them, and there was a severe infection under the tongue. In the orbits of both eyes and in the sublachrymal pits many awns had become embedded.

Case No. 21: The front teeth were locally infested with awns in the gums of front and rear sides of the incisors. Both upper and lower

molars were infested on both sides, with many awns in the inner surface of the cheek, in the openings of ducts beneath the tongue, and in the sides of the jaw. Some had penetrated the jaws, others were found in the orbit of one eye, and in one sublachrymal pit. One large awn had entered the nasal cavity and lay in a mass of pus.

Figure 7. Bearded Seeds of Squirrel-tail Grass in Blinded Eye of Sheep. Abscesses on Face from Same Cause.

Figure 8. Lamb Blinded by Awns of Squirrel-tail Grass. Note Abscesses on Face.

SUMMARY OF EXAMINATIONS OF TWENTY-ONE HEADS SELECTED AT RANDOM FROM A LARGE PILE OF SHEEP CARCASSES

Check x indicates the organ was found to be infested with awns.

Sheep No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
Eye	x				x			x	x	x	x		x	x	x	x	x	x	x	x	x	15
Sublachrymal pit	x	x			x		x	x		x	x	x		x	x	x	x	x	x	x	x	16
Front teeth	x			x	x	x	x	x	x	?	x	x		x	x	x	?	x	x	x	x	16
Upper molars		x		x	x	x	x	x	x	?	x	x		x	x	x	x	x	x	x	x	18
Lower molars	x	x		x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	19
Palate								x			x	x			x						x	5
Gums						x						x									x	3
Under tongue					x	x	x	x		x		x				x			x	x		9
Upper lips												x	x		x	x						4
Lower lips												x	x			x			x			4
Inner surface of cheek							x															1
Surface of tongue												x									x	2
Ear			x								x	x		x	x	x						6
Nasal passage						x		x				x			x						x	5
Eustachian tube															x							1
Upper jaw ulcerated												x		x								2
Lower jaw ulcerated				x	x								x	x								4

The foregoing twenty-one examinations were made from the heads of range sheep which had been brought in to be fed hay during the lambing season. The ewes were grade Rambouillet and, while they were not young, most of them originally had fairly good teeth.

The hay contained a large percentage of squirrel-tail grass. It was fed in feed racks that did not permit of the ewes getting the hay with any degree of ease. Some fed standing on their hind legs, while others had their heads half buried in the hay. Because of these feed racks, the ewes were infested with more of the awns than they ordinarily would have been if the hay had been scattered on the ground or fed in racks in which the hay would have been more accessible.

Relation of Age to Injury:

It was noticed that the sheep which were suffering most from squirrel-tail injuries were the yearling lambs and the aged ewes,

Figure 9. A Triple Loss.

although there was general infestation of all ages. Possibly the young sheep were more heavily infested because their bodies are nearer the ground and their skin more tender. Of course, the old ewes are injured most because (1) they have not the vitality of the younger and middle-aged sheep, and (2) their teeth are usually broken or lost or spread so that the awns become readily lodged, causing serious mouth trouble, with the result that the ewe is either very reluctant to eat or entirely refuses to eat, and soon is found standing apart from other animals in the flock slowly dying of starvation.

Relation of Breed to Injury:

Merino and Rambouillet sheep are injured more than the more open-wooled and smooth-bodied breeds. The fine wool of the Merino holds the awns more tenaciously than other types of wool. Sheep with open wool and clean faces are not so seriously injured as are the sheep of

Merino breeding, which have considerable wool about the eyes. The Merinos gather more awns because of the wrinkles around the neck and head.

Economic Loss:

When the wool of the back, neck and flanks is full of the pricking bearded seeds, the sheep walk stiffly; every motion hurts as if the skin were full of slivers. The natural easy gait is gone, and, instead, the bodily movements are constrained and stiff. This is all due to the pain produced by the piercing awns and the thick mass of seeds embedded in the wool and skin. Eventually the skin loses its pliability and becomes hard, and the wool feels rough and dry on being handled. The sheep stretches, rubs itself, bites the wool. It may become so badly infested that the masses of bearded seeds will give all the wool a brownish color. Naturally, as a result, the sheep loses flesh and the wool is materially damaged. The animal refuses to eat and dies of starvation or becomes so weakened as to die from any disease to which it may be

Figure 10. Saving the Hides.

subject. When the ewe is blinded by the awns or when her mouth is extremely sore and tender, she ceases to feed and may die of blood poisoning, of starvation, or of any disease to which she is subject.

Mortality:

The loss to the owner because of awn infestation is greater than the actual loss by deaths. This is due to the fact that (1) the wool depreciates very materially in sale value; (2) the loss of condition not only affects the ewe but the subsequent growth of her lamb, and (3) she gives little or no milk. (4) The useful life of the ewe is shortened materially by loss of condition, loss of teeth, etc., which makes her prematurely an old ewe so far as her worth on the range is concerned.

The actual deaths vary in different bands, due to a difference in the breed, age, and manner of feeding. However, the death of the ewe at lambing-time usually means the death of the lamb, so the loss is doubly serious at this period of the year. Unless preventive measures are taken, the mortality is high, even from a short feeding season on hay containing a considerable percentage of squirrel-tail grass.

Especially Injurious During Lambing Season:

The lambing season is the most trying part of the year to the ewe. This is especially true if she has twin lambs. It is a time of the year when she needs comfort, kind attention and an abundance of milk-producing feeds, otherwise the loss of ewes and lambs is bound to be high. Even under the best of conditions, where several thousand ewes are lambed, the number of doubtful lambs runs from 1 to 3 per cent, depending upon the character of the feed, the age of the ewes, and the skill and experience of the lambing crew. By a doubtful lamb is meant one that requires more or less individual attention in order to save and

Figure 11. Sheep Eating Squirrel-tail Hay from Feed Rack. The head is half buried in the hay. This method of feeding is sure to cause losses.

rear it. If the lambing conditions are not quite right, the number of doubtfuls may run into a horde. In order to reduce losses to the smallest possible point, the sheepman should keep three things in mind when he brings ewes in from the range, and puts them into the lambing corrals. These three points are (1) to give hay and other feeds that will make the most milk; (2) to make the lambing results more certain by insuring against possible heavy loss due to starvation and severe storms, and (3) to eliminate, so far as practicable, the small but regular losses due to "outlaw" ewes, poor weak ewes, weak lambs, twin lambs, predatory animals, rough handling, lack of attention, and insufficient help. However, even if all the conditions are ideal, if the

hay contains squirrel-tail awns in any large quantity, large losses of ewes and lambs may be expected with always a very high percentage of lambs in the doubtful list.

Kleinheinz in his book on "Sheep Management" says: "Timothy and marsh hay should at no time be offered as feed to sheep. Too much emphasis cannot be placed upon this statement, for timothy hay with its coarseness and woodiness has caused the loss of thousands of sheep annually in this country from constipation." This statement is verified by many western sheepmen who have had large losses from feeding a straight diet of timothy and marsh hays. A few of them firmly believe, although erroneously, that timothy hay when fed for a prolonged period contains sufficient poison to kill sheep.

Squirrel-tail grass, when put up in hay, is usually associated with timothy and marsh grasses and grasslike plants, and it is little wonder

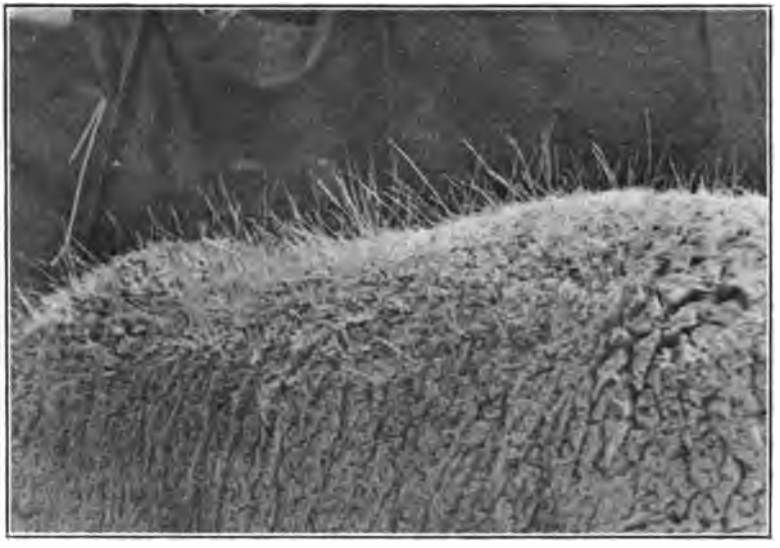

Figure 12. Bearded Seeds of Squirrel-tail Grass in Back of Sheep.

that large and abnormal losses occur when such a combination of feeds may form in many cases the sole diet of the ewe and her lamb.

Feeding Squirrel-tail Grass in Hay:

If one is compelled to feed squirrel-tail grass to sheep, it should never be fed in feed racks. It is far better to scatter the hay thinly over the ground, for this will give the sheep the greatest freedom in the selection of what they eat, and they will, as a result, reject and refuse to a large degree the heads of the squirrel-tail grass. Further, this manner of feeding largely prevents the awns from infesting the external part of the body. Injurious results can be prevented to some extent by casting aside at the time of loading all hay in which the squirrel-tail grass makes up the greater part of the bulk, as it so frequently does in various parts of the hay in the stack.

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ARROW-GRASS

A New Stock-Poisoning Plant

(*Triglochin maritima*)

By

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Assisted by

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ACKNOWLEDGMENT

The Nevada Agricultural Experiment Station takes pleasure in thanking A. O. Larson of Castle Dale, Utah, for suggestions which led to the study of the poisonous properties of Arrow-Grass, and to Mr. G. W. Walts of Reno, Nevada, for valuable information and assistance.

ANNOUNCEMENT

In July, 1918, the Nevada Agricultural Experiment Station published Bulletin No. 95 entitled "Range Plants Poisonous to Sheep and Cattle in Nevada," by C. E. Fleming, head of the Department of Range Management. Hundreds of requests for copies were received from stockmen and forest rangers in Nevada and California. The Foreign Press Bureau of the Committee on Public Information requested 500 copies for distribution in South American countries. Although the number printed was unusually large, the entire edition of this bulletin was soon exhausted and republication has become desirable.

Since the publication of Bulletin No. 95 long series of feeding experiments with poisonous plants have been made at the Nevada Station. Before publishing another general bulletin on the subject of range plants poisonous to sheep and cattle it seems best to print a short series of bulletins giving the results of feeding tests made with each poisonous plant.

We plan later to bring together the results of all the new experiments with all former information on the subject in another illustrated general bulletin on poisonous plants.

S. B. DOTEN,
Director.

Figure 1. Typical plant of Arrow-Grass, showing cluster of leaves and two flower stalks.

Figure 2. Arrow-Grass, growing among other plants and grasses.

SUMMARY

1. Recent experiments conducted by the Agricultural Experiment Station of the University of Nevada show that under certain conditions the grasslike plant commonly known as Arrow-Grass is poisonous to both sheep and cattle.

2. Arrow-Grass looks like the common grasses; and often grows among them in wet soils especially where the ground contains alkali.

3. Figures 1, 2 and 3 of this bulletin give a good idea of the general appearance of the plant.

4. Arrow-grass contains an unknown substance, which is sometimes broken up in the stomach of the animal, liberating a deadly poison—hydrocyanic ("prussic") acid gas.

5. Animals fatally poisoned by Arrow-Grass breathe very rapidly at first; they tremble, breathe through the mouth, walk around stiffly, have spasms and go down in convulsions. Later they breathe more slowly and with increasing difficulty, spasms continuing at intervals until death, which occurs in from half an hour to three hours.

6. An animal must eat a large dose at one time in order to be poisoned. Small doses eaten at frequent intervals or moderate quantities eaten daily have no harmful effects.

7. Arrow-Grass cut and dried in hay is far more dangerous and deadly than the green plant.

8. When the body of an animal dead of Arrow-Grass poisoning is cut up there is little indication of the cause of death. There is usually some congestion of the lungs and of the fourth stomach, but neither condition is characteristic of this plant alone.

9. Because of the nature of the poison and because death follows poisoning so promptly, there is little hope of finding methods of treating and curing animals seriously poisoned by Arrow-Grass.

10. Places where Arrow-Grass grows very thickly should be fenced off. Considerable effort should be made to prevent Arrow-Grass from being cut, dried and put up in hay.

ARROW-GRASS

A New Stock-Poisoning Plant

(*Triglochin maritima*)

IN THE AUTUMN OF 1918 we were informed by A. O. Larson of Castle Dale, Utah, that cattle had died in southern Utah from eating a plant known in that region as "goose-grass." Fatal poisoning had been caused by the green plants in pastures and more especially by the dried plant in hay. Specimens sent by Mr. Larson to the Nevada Station were identified as "arrow-grass" or "sour-grass" (*Triglochin maritima*). The small amount of material sent from Utah was insufficient to produce any symptoms of poisoning in sheep; however, as this plant is common in wet and semialkaline places in the vicinity of Reno, experimental feedings of larger amounts were begun at once and continued throughout the spring and summer of 1919. These feeding tests showed clearly that under certain conditions the plant is poisonous to both sheep and cattle. The results of these tests are given in detail in this bulletin.

Figure 3. In grass meadows it is hard to find Arrow-Grass before it blooms.

Common Names.

Triglochin is known by three common names — arrow-grass, goose-grass, and sour-grass. Because arrow-grass is the name most commonly and universally used, its adoption and use by stockmen is recommended.

Description of Plant.

This poisonous plant belongs to a little family of plants known as the arrow-grass family. It grows in bright-green clumps and bunches, so much like grass that it is hard to find in the midst of grasses and other plants until the flower heads and pods have formed. It grows in scattered clumps about 12 inches wide, or in irregular patches which may be from 10 to 20 feet or more across. The flat clumps or bunches of arrow-grass grow from 6 to 12 inches high; and each clump of leaves bears a straight slender flower-stalk, growing to

a height of from 12 to 30 inches. The flowers and seed-pods form a slender cluster from 6 to 12 inches long. The flowers themselves are tiny greenish things, and are soon followed by the oblong three-sided seed-pods.

The leaf of arrow-grass is slender, bright-green, very much like grass or sedge. Still it may readily be told from grass by the fact that it is not flat like a grass-blade, but is thick and spongy, flat on one side and round on the other. The leaf of arrow-grass is soft, not wiry and tough like that of a sedge. The leaves are attached to an underground stem, about as thick as a lead-pencil, which pushes its way along beneath the surface, sending up leaves and sending down numerous fibrous roots. The general appearance of the plant is shown in Figures 1, 2 and 3. A flower cluster and a cluster of seed-pods are shown in Figures 5 and 6.

Figure 4. Cross-section of Arrow-Grass leaf, greatly magnified. (X20). The leaf of Arrow-Grass is thick and spongy, not thin and flat like that of ordinary grasses.

Distribution.

Arrow-grass is widely distributed over the northern half of the world. In North America it is found from New Jersey to California and from Labrador to Alaska. On the sea coast it grows in salt marshes; inland it may be found in wet alkaline soils and along the edges of sloughs, associated with grasses and sedges and other plants which require much water.

Three species of arrow-grass occur throughout North America in wet saline or semialkaline soils. At least two of them occur in the pastures and meadows in Nevada, but *Triglochin maritima* being the larger plant and the most common is probably the one responsible for most of the stock losses that occur from eating this plant. It is not definitely known if the other species are sufficiently abundant and poisonous to be dangerous.

Losses Due to Arrow-Grass.

But little is known concerning the extent of animal losses caused by arrow-grass. It has not been generally considered poisonous, and many losses attributed to other causes may have been due to this plant. Dried arrow-grass mixed with hay or fed free from mixture is readily eaten. The green plant does not seem to be distasteful to animals, and it is sometimes eaten greedily, although many other poisonous plants, especially those containing alkaloids, are so bitter that stock will eat them only when forced to do so by extreme hunger.

Because of its rather pleasing and acceptable taste and because of the fact that the plant often grows in almost pure patches from a few feet to rods across and produces a large quantity of forage, it would seem easier for animals either on pasture or on hay to get a fatal dose of arrow-grass than of poisonous plants which grow scattered here and there amid other foliage.

The Poisonous Principle of Arrow-Grass.

An air-dried sample of the plant (*Triglochin maritima*) used in the feeding experiments was examined in the Station Laboratory and was

found to possess cyanogenetic properties, *i. e.*, would yield hydrocyanic acid ("prussic" acid) upon suitable treatment.

That this might be expected was, in a measure, suggested by the symptoms observed in the feeding experiments. In the literature it appears that Greshoff[1] found from 0.02% to 0.6% of hydrocyanic acid

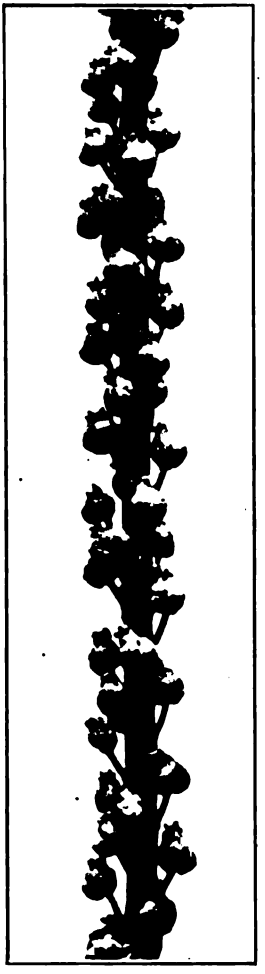

Figure 5. Flowers of Arrow-Grass magnified (X2). Flower is small, greenish, and insignificant.

Figure 6. Seed-pods of Arrow-Grass magnified (X2).

in *Triglochin maritima*. Later Blanksma[2] in working with the same plant found hydrocyanic acid in amounts varying from 0.056% to 0.184%.

[1]Greshoff, M.: A New Natural Group of Plants Containing Hydrocyanic Acid. Pharm. Weekblad, 45. 1165–69, 1907.

[2]Blanksma, J. J.: Hydrocyanic Acid in Sour-Grass (Triglochin). Pharm. Weekblad, 50. 1295–1302.

In the plants known as cyanogenetic plants, substances have been found in which hydrocyanic acid is in combination with other compounds. As an example of such compounds may be cited amygdalin, a compound, which will yield hydrocyanic acid and benzaldehyde, found in the bitter almond. Compounds of this sort may be made to give up their hydrocyanic acid by the action of suitable reagents, such as by the action of acids upon amygdalin. Another method of breaking off the hydrocyanic acid is by the action of certain ferments. Almost invariably the cyanogenetic substance is found to be accompanied in the plant by a ferment most suitable for that substance. When the cells of the plant are broken the ferment has opportunity to act upon the hydrocyanic acid-holding compound and the acid is liberated.

The poisonous properties of the cyanogenetic plants may be reasonably thought to be due to hydrocyanic acid liberated as described above. That other poisons are present may be possible and has been suggested, but laboratory examination has failed to disclose the presence of notable amounts of other poisonous substances such as alkaloids or saponins.

In the sample submitted, which had lost 79.2% of moisture in drying, there was found 0.264% hydrocyanic acid. Calculated to the original green weight of the plant, this is equivalent to 0.0549% hydrocyanic acid in the original plant. That there is a possibility that a part of the hydrocyanic acid originally present in the green plant was lost in drying, has been shown to be the case in the drying of sorghums. This would make the above figure lower than it should be for the green plant. Dowell[3] showed that in the drying of sorghum approximately three-fourths of the acid is set free.

Laboratory evidence in this case shows that we have been dealing with a cyanogenetic substance, the nature of which will form the subject of a more technical paper from this Station in the future.

Poisonous plants of this type sometimes appear to have an erratic action both in feeding experiments and also when animals are grazing at will. Apparently the grazing of sheep and cattle upon such plants has not been accompanied with fatal results in every case. The areas from which the samples used in these experiments were obtained have been and are used for the grazing of sheep with the only results that at times lambs succumb. Cattle have been fed safely upon sorghums which unquestionably contained hydrocyanic acid and which at other times and under different conditions of feeding caused fatal results. The leaves of the choke-cherry contain hydrocyanic-producing substances, but poisoning does not necessarily accompany natural feeding, although fatal results have been reported. Linseed cake has been the subject of many experiments,[4] and has been found to contain lethal doses of hydrocyanic acid in the amounts fed, but still was successfully used in feeding and fattening.

In explaining such a state of affairs it is necessary to consider all of the possible factors which contribute to the action of these compounds. Auld[4] has pointed out that under digestive conditions cyanogenesis is likely to be inhibited. He shows that the presence of acids, alkalies, salts, cellulose and glucose all tend to prevent the liberation of the

[3]Dowell, C. T.: Cyanogenesis in Andropogon Sorghum. J. Agr. Res. (1919) 16, 17, 175–81.
[4]Auld, S. J. M.: Cyanogenesis under Digestive Conditions. Jour. Agr. Sci. (1913) 5 408–38.

poison, and that in the cases of feeding in which poisoning occurs it is likely that there is some element which interferes with the inhibition which would normally take place. The possibility of the formation of hydrocyanic acid in the food before feeding is very likely in cases in which the feeding stuff is manipulated or prepared before administration. In the case of green food, only the rupturing of the cells is sufficient to produce the free poison, and in the case of the dry material, which is generally more or less broken up, it is only necessary to introduce moisture to produce the free poison. If inhibition can be due to an alkaline medium, the normal conditions in the mouth during eating and in the rumen of the animal would have a protective action and would tend to prevent poisoning. Anything interfering with normal mastication and the attendant mixing of saliva with the food would evidently interfere with the inhibitory process and end with disastrous results. Auld (loc. cit.) points out the protective effect of cellulose and glucose, and that these carbohydrates have an inhibitory action on the evolution of hydrocyanic acid has been observed by other investigators with other plant materials. In fact, it has been recommended[3] that glucose be used as an antidote in cases of poisoning from this source. As a matter of fact, it is probable that the administration of glucose would have but little effect if done after the symptoms of acute poisoning have developed. However, if a suspicious food was to be fed, it might be mixed with a glucose-containing material as a precautionary measure.

Another and equally important factor is that of the physical condition of the animal when fed; the state of its health and whether the food in question is taken upon a partially filled or empty stomach. It would appear in the case of sorghum, for example, that cows turned into sorghum would be fatally poisoned if nothing had been eaten for a short time previously; but if they were first fed and then allowed access to the same plants no poisoning would follow.

The Season of the Year when Arrow-Grass Is Poisonous.

Feedings were made with arrow-grass cut both in early summer and during fall. It appeared equally poisonous at both seasons. There is good reason for believing that the plant is toxic during the entire period of its growth.

The Part of the Plant which Is Poisonous.

The greater part of arrow-grass consists of the leaves, the flower stalk making only a small portion of its total weight. The leaves have been conclusively proven to be poisonous. We have not found out whether the flower stalks are poisonous because they are more or less tough and unpalatable and make up only a minor part of the total weight of the plant. The roots are so firmly held down by their fibrous growth that there is little or no chance of their being eaten.

The following tables give the feeding tests which were made with sheep and cattle in the fall of 1918 and the spring and summer of 1919; all the animals were fed the fresh green leaves except a single sheep weighing seventy pounds which was fed three-fourths of a pound of the green fruits without results:

[3]Peters, A. F., Slade, H. B., and Avery, Samuel: Poisoning of Cattle by Common Sorghum and Kafir Corn. Nebraska Station Bulletin No. 77.

SHEEP-FEEDING TESTS WITH GREEN MATERIAL, 1918–1919

Animal No.	Weight of animal	Date	Time fed	Amount fed	Time symptoms appeared	Time of death or recovery	Final result
42	70 lbs.	10-7-1918	4:40 p. m.	¼ lb.	None		
40	100 lbs.	10-7-1918	4:30 p. m.	1 lb.	None		
39	97 lbs.	10-8-1918	3:10 p. m.	4½ lbs.	3:25 p. m.	4:13 p. m.	Death
42	75 lbs.	10-10-1918	4 p. m.	2 lbs.			Slightly sick
		10-15-1918	11:40 a. m.	2 lbs.	12:05 p. m.	1:40 p. m.	Death
46	72 lbs.	10-29-1918	2:30 p. m.	3 lbs.	None		
	75 lbs.	11-7-1918	9 a. m.	2¾ lbs.	None		
26	75 lbs.	4-12-1919	9 a. m.	1 lb.	None		
29	81 lbs.	4-15-1919	9:30 a. m.	1 lb.	None		
26	75 lbs.	4-15-1919	9:40 a. m.	1½ lbs.	None		
	73 lbs.	6-3-1919	11:40 a. m.	1½ lbs.	12:50 a. m.	1:15 p. m.	Death
46	70 lbs.	6-3-1919	1:15 p. m.	1 lb.	None		
		6-4-1919	10:50 a. m.	1½ lbs.	None		
		6-5-1919	10 a. m.	1½ lbs.	None		
		6-6-1919	10 a. m.	2 lbs.	None		
		6-7-1919	2 p. m.	2½ lbs.	None		
		6-11-1919	2 to 4 p. m.	2½ lbs.	4:30 p. m.	7 p. m.	Recovery
		6-12-1919	9:20 a. m.	2½ lbs.	9:30 a. m.	9:55 a. m.	Death
29	80 lbs.	6-11-1919	9 to 10:20 a. m.	1½ lbs.	10:30 a. m.	10:55 a. m.	Death

As a result of the twenty feeding tests, 7 sheep were poisoned, 5 of which died. The weight of green material required to make a sheep sick or to kill it varied from 1½ pounds to 4½ pounds, the average fatal dose being approximately 2.4 pounds. Because of the extremely irregular way in which plants containing hydrocyanic acid act on animals, it would be difficult to state accurately just how much of the plant is required to kill a sheep or to make it sick.

However, the above tests demonstrate conclusively that arrow-grass is a plant containing an active poison, and, although the amounts necessary to produce sickness or death may seem high, in reality they are not; for the plant is made up of a rather open cellular structure containing a high percentage of water. Further, when poisoning does take place death is likely to follow; this is shown by the fact that of 7 animals poisoned 5 died. Four of the deaths were caused by 2½ pounds or less of green material.

A series of feeding tests with cattle made in spring, summer and autumn with green arrow-grass failed to cause poisoning. The tests are summarized in the table at the top of page 13.

Two pounds of green arrow-grass had no effect on Steer No. 735. In October this animal ate an average of 15¾ pounds daily for 7 days or a total quantity of 110¼ pounds, with no bad effects. The material for this test as shown in the table was collected during October. The June feeding tests also resulted negatively.

These results cannot be taken to mean that fresh green arrow-grass is not poisonous to cattle; for we must constantly keep in mind the irregular and apparently inconsistent action of plants containing hydrocyanic acid. There is a possibility that under different conditions of feeding and at another time the feeding of the same quantity or even less would have caused poisoning. Many valuable forage plants in the sorghum group contain hydrocyanic acid; and yet they are ordinarily fed without causing losses. However, on the other hand, rather serious losses in cattle have been caused by the sorghums. With arrow-grass, the same erratic action may be expected. This test would seem to indicate that pastures where arrow-grass grows are ordinarily not dangerous to cattle; still, there is always a possibility that they may eat just the right amount at the right time with deadly results.

CATTLE-FEEDING TESTS WITH GREEN LEAVES, 1918–1919

Animal No.	Weight of animal	Date fed	Time fed	Amount fed
735	530 lbs.	10-10-1918	3 p. m.	2 lbs.
	515 lbs.	10-10-1918	4 p. m.	9½ lbs.
		10-12-1918	9 a. m.	11 lbs.
		10-15-1918	9 a. m.	19 lbs.
		10-22-1918	12 p. m.	20 lbs.
		10-23-1918	10 a. m. / 2 p. m.	14 lbs.
		10-26-1918	2 p. m.	23 lbs.
		10-27-1918	9 a. m.	
		10-27-1918	12 m.	10 lbs.
		10-27-1918	4 p. m.	4 lbs.
1	137 lbs.	4-15-1919	11:30 a. m.	1½ lbs.
		6-4-1919	10 a. m. / 8:30 p. m.	13¼ lbs.
		6-5-1919	1 p. m. / 8 p. m.	8½ lbs.
		6-6-1919	8 a. m. / 1 p. m.	6½ lbs.
		6-7-1919	3 p. m.	2¼ lbs.
		6-8-1919	2 p. m.	4 lbs.
		6-10-1919	1 p. m.	8½ lbs.
7	141 lbs.	6-10-1919	5:30 p. m. / 10:30 p. m.	8¼ lbs.
		6-11-1919	8:30 a. m. / 5 p. m.	13¼ lbs.

Feeding Arrow-Grass in Hay.

The following feeding tests were made with sheep and cattle to determine the effect of various proportions of dry arrow-grass when put up in hay and fed. The plant material for these feedings was collected in 1919 on a ranch near Reno. One lot of 26½ pounds of fresh arrow-grass was collected June 3, 4 and 5 and air-dried to 5½ pounds. Another lot of 38¾ pounds was collected on August 9 on the same ranch and air-dried to 9 pounds.

SHEEP-FEEDING TESTS WITH AIR-DRIED ARROW-GRASS

Animal No.	Weight of animal	Date fed	Time fed	Amount fed	Time symptoms appeared	Time of death or recovery	Final result
60	94 lbs.	8-5-1919	4 p. m.	8 ozs.	4:50 p. m.	5:50 p. m.	Death
37	88 lbs.	8-5-1919	4:20 p. m. 4:45 p. m.	12 ozs.	5:30 p. m.	Night	Recovery
58	101 lbs.	8-6-1919	10 a. m. 11:30 a. m.	4 ozs.	5:15 p. m.	9:30 p. m.	Recovery
53	109 lbs.	8-6-1919	10 a. m. 11:30 a. m.	4 ozs.	----------	----------	Negative
54	115 lbs.	8-6-1919	2:30 p. m. 3:30 p. m.	5¼ ozs.	4 p. m.	4:35 p. m.	Death
58	100 lbs.	8-7-1919	1:30 p. m. 2:30 p. m.	4 ozs.	3:20 p. m.	7 p. m.	Recovery
51	96 lbs.	8-15-1919	3:30 p. m.	1 oz.	----------	----------	Negative
53	105 lbs.	8-15-1919	3 p. m.	1 oz.	----------	----------	Negative
58	100 lbs.	8-16-1919	8:50 a. m.	3 ozs.	----------	----------	Negative
51	96 lbs.	8-20-1919	6:50 a. m.	1 oz.	----------	----------	Negative
37	87 lbs.	8-20-1919	7 a. m.	2 oz.	----------	----------	Negative
61	100 lbs.	8-20-1919	7:20 a. m.	3 ozs.	8:30 a. m.	10:15 a. m.	Death
62	82 lbs.	8-20-1919	7:30 a. m.	2¼ ozs.	8:03 a. m.	9 a. m.	Death

TESTS WITH A YEARLING CALF

1	133 lbs.	8-8-1919	9:30 a. m.	7 ozs.	9:50 a. m.	10:20 a. m.	Death

Thirteen feeding tests were made with the air-dried material fed to sheep, six of which tests either made the animal very sick or else caused death. These tests prove conclusively that small amounts of the dried plant are highly poisonous to sheep. The smallest amount which was fatal to a sheep was 2¼ ozs., the average fatal dose being approximately

4.64 ozs. Again it is interesting to note the high percentage of deaths among the poisoned animals.

The one feeding test made with the yearling calf was so conclusive that it was considered unwise to sacrifice any more cattle. The small amount fed, only 7 ozs., readily produced typical poisoning symptoms, and its action was so characteristic and rapid that there appeared to be no immediate need of other tests with cattle.

The above feedings were made by uniformly mixing with alfalfa the small amounts of arrow-grass tabulated. Therefore, these tests show very clearly that there is considerable danger or risk of loss when arrow-grass is cut and put up with hay and fed to live stock.

SHEEP-FEEDING TESTS WITH SMALL AMOUNTS OF ARROW-GRASS IN HAY

Animal No.	Weight of animal	Date fed	Time fed	Amount fed
62	82 lbs.	August 9	1:10 p. m.	1 oz.
			2:10 p. m.	1 oz.
			3:10 p. m.	1 oz.
			4:20 p. m.	1 oz.
			Total	4 ozs.
51	94 lbs.	August 8	9:50 a. m.	½ oz.
			10:50 a. m.	½ oz.
			11:45 a. m.	½ oz.
			12:50 p. m.	½ oz.
			2:10 p. m.	½ oz.
			3:05 p. m.	½ oz.
			4:10 p. m.	½ oz.
			5:10 p. m.	½ oz.
			6:10 p. m.	1 oz.
			Total	5 oz.
51	97 lbs.	August 21	10:30 a. m.	½ oz.
			11:30 a. m.	½ oz.
			1:20 p. m.	1 oz.
			2:30 p. m.	½ oz.
			3:30 p. m.	½ oz.
			4:30 p. m.	½ oz.
			7:00 a. m.	1 oz.
			8:10 p. m.	½ oz.
			9:00 p. m.	½ oz.
		August 22	12:10 a. m.	1 oz.
			7:00 a. m.	1 oz.
			8:00 a. m.	1 oz.
			9:00 a. m.	½ oz.
			10:00 a. m.	½ oz.
			11:00 a. m.	½ oz.
			12:00 m.	½ oz.
			12:50 p. m.	½ oz.
			1:45 p. m.	½ oz.
			2:30 p. m.	½ oz.
			3:15 p. m.	½ oz.
			4:00 p. m.	½ oz.
			4:45 p. m.	½ oz.
			5:30 p. m.	½ oz.
			6:10 p. m.	½ oz.
			7:00 p. m.	½ oz.
			7:45 p. m.	½ oz.
			8:30 p. m.	½ oz.
		August 23	6:40 a. m.	1 oz.
			7:20 a. m.	½ oz.
			8:00 a. m.	½ oz.
			8:40 a. m.	½ oz.
			9:20 a. m.	½ oz.
			10:00 a. m.	½ oz.
			10:40 a. m.	½ oz.
			12:00 m.	½ oz.
			1:00 p. m.	½ oz.
			1:30 p. m.	½ oz.
			2:00 p. m.	½ oz.
			2:30 p. m.	½ oz.
			3:00 p. m.	½ oz.
			3:30 p. m.	½ oz.
			4:00 p. m.	½ oz.
			4:30 p. m.	½ oz.
			4:50 p. m.	½ oz.
			5:10 p. m.	½ oz.

Feeding of Small Amounts at Stated Intervals Mixed with Hay.

The object of this series of feedings was to determine whether small amounts of air-dried arrow-grass (the total of which if fed at one time would cause sickness or death) would be harmful when fed a little at a time at various intervals. None of the animals were affected except No. 62, which showed symptoms of poisoning after the fourth 1-oz. dose.

The above feeding tests show that there is little or no cumulative effect of small doses fed at short intervals or over a long period of time. Previous to these tests a sheep had been fed 4 ozs. of air-dried arrow-grass which readily killed the animal. However, when 4 ozs. of similar material was fed in 1-oz. doses to a sheep at hourly intervals only sickness was produced. On August 8 at 9:50 a. m. a sheep was given ½ oz. and thereafter ½-oz. feedings were made at approximately hourly intervals until 6:10 p. m. when 1 oz. was fed. In all between 9:50 a. m. and 6:10 p. m. 5 ozs. had been fed without producing any visible symptoms of poisoning.

On August 21 at 10:30 a. m. a prolonged feeding test was commenced and continued until 5:10 p. m., August 23, during which time 45 separate feedings were made of five 1-oz. feedings and forty ½-oz. feedings or a total of 25 ozs. with negative results.

From these feedings it appears that there is no cumulative action of the poisonous principle of arrow-grass when eaten in small amounts of less than 1 oz. at short intervals. It may therefore be safely concluded that an animal may eat many small amounts either in hay or on pasture with little danger. Thus, if small quantities of the dried material are uniformly scattered through the hay, there is not much to worry over, so far as the health of the animals is concerned. On the other hand, if there is any considerable quantity in the hay, fatal results may be expected especially if fine, broken material collects in the bottom of the feed racks. Dry arrow-grass is very brittle, easily broken, and may very readily sift to the bottom along with seeds, chaff, and other material. If this takes place, then there is a possibility of fatal poisoning, even though there is only a small amount of the plant in the hay.

DETAILED DESCRIPTION OF TYPICAL CASES OF ANIMAL POISONING

Case No. 1—No. 39.

A sheep weighing 97 pounds was fed 4½ pounds of green arrow-grass leaves at 3:10 p. m. October 8, 1918. The animal appeared sick at 3:25 p. m. within fifteen minutes after feeding. Muscular spasms commenced at 3:30 p. m.; hindlegs pulled up under body; frequent champing of jaws, breathing hard and audible. At 3:40 the sheep was breathing through the mouth which was held wide open with the tongue hanging out; temperature, 102; respiration, 30. At 3:50 p. m. spasms continued; 3:55 p. m., respiration, 21; at 3:58 p. m., severe spasms commenced and breathing practically stopped; at 4:03 p. m., respiration 12, with long intervals between breaths. Expulsion of breath forcible and plainly audible; at 4:12 p. m. respiration had fallen to 8. Death occurred at 4:13 p. m.

Autopsy showed the jejunum severely congested; spleen dark and mushy; kidneys congested; lungs slightly congested; other organs all appeared normal.

Case No. 2—No. 42.

A ewe weighing 75 pounds was fed 2 pounds of green arrow-grass leaves at 11:40 a. m.; at 12:05 p. m. she was walking with a stiff peculiar gait the hindlegs far apart and held back. Soon muscular twitchings commenced. At 12:25 p. m. the respiration was 25. At 12:30 she fell down, displaying spasms with a peculiarly regular up-and-down movement of the head. Spasms occurred at short intervals until a little before death. At 1:28 p. m. the respiration was 19. At 1:37 p. m. the mouth was held open with the tongue out and breathing had almost ceased. Death occurred at 1:40 p. m.

Autopsy showed moderately congested abomasum, spleen dark and mushy, small intestine congested, lungs slightly congested; all other organs apparently normal.

Case No. 3—No. 26.

A yearling wether weighing 73 pounds was fed 1½ pounds of green arrow-grass leaves at 11:40 a. m. At 12:50 p. m. he was down on his

Figure 7. Sheep in early stages of Arrow-Grass poisoning.

belly with legs stretched out, mouth open; very audible breathing through mouth, and distinct twitching movements of head and rolling of eyes. At 1 p. m., respiration 16, temperature 103.2. Had a series of spasms at regular short intervals until death, which occurred at 1:15 p. m.

Autopsy showed fourth stomach slightly reddened, small hemorrhages on heart; spleen darkened; all other organs apparently normal.

Case No. 4—No. 46.

A ewe weighing 70 pounds was fed 2½ pounds of green leaves of arrow-grass between 2 p. m. and 4 p. m. She commenced to feel distressed and acted unnatural almost as soon as the feeding was finished, standing with head down, appearing very dull and caring little to move about. This state of inactivity was maintained until 5:45 p. m. when she commenced to brighten up, and at 7 p. m. appeared quite normal, for she was eating a little hay.

Case No. 5—No. 46.

The same sheep as in Case No. 4 was again fed the next day 2½ pounds at 9:20 a. m. and was very sick by 9:30 a. m. She was breathing through the open mouth, with frequent twitching movements of the muscles of the neck, wrinkling movements of the lips and a chewing movement of the jaws. At 9:45 a. m. she was down on her side with spasms most of the time until 9:50 a. m., when she began to regurgitate

Figure 8. Sheep down in convulsions, Arrow-Grass poisoning.

Figure 9. Sheep dying from Arrow-Grass poisoning.

food which passed out both through the mouth and nostrils. Death occurred at 9:55 a. m., thirty-five minutes after she was fed.

Autopsy (by Dr. R. C. Louck): Slight congestion of fourth stomach, large intestine congested; small hemorrhages on ventricles; all other organs apparently normal.

Case No. 6—No. 29.

A yearling lamb weighing 80 pounds was fed three-fourths of a

pound of green material between 9 a. m. and 10:20 a. m. He was sick at 10:30 a. m. ten minutes afterwards. Breathing through the mouth was very audible; and the animal was soon down on its side. The respiration was 50, temperature 101.4. He lay on his side with difficult breathing and series of spasms at frequent intervals until shortly before death, which occurred at 10:55 a. m., thirty-five minutes after feeding.

The autopsy showed small hemorrhages of the heart; all other organs appeared normal. Because of regurgitation shortly before death, the lungs contained food material.

Case No. 7—No. 60.

A ewe weighing 94 pounds was fed 8 oz. of the dry leaves at 4 p. m. At 4:50 p. m. she was down and unable to rise. Peculiar jerky movements of the head took place. At 5 p. m. she began having a series of convulsive spasms at intervals of four or five minutes until death, which occurred at 5:50 p. m. Just before death she vomited a little.

Autopsy showed slight inflammation of colon; severe congestion of both lungs; slight hemorrhages in the endocardium of the ventricles.

Case No. 8—No. 37.

A ewe weighing 83 pounds was fed 12 ozs. of the dry leaves between 4:20 p. m. and 4:45 p. m. At 5:30 p. m. she was dull and could hardly be induced to get up. Slight jerky movements of the muscles of the head and neck took place, becoming more pronounced until 7:20 p. m. When next observed, at 9:30 p. m., she was much better, being up and walking about, but still very much indisposed. Next morning at 8 a. m. she appeared to have fully recovered.

Case No. 9—No. 58.

A ewe weighing 101 pounds was fed 4 ozs. of the dry leaves between 10 and 11:30 a. m. At 5:15 p. m. she was breathing rapidly, the respiration being 150 per minute. This condition lasted until 7 p. m. No other symptoms were observed. Next morning she was eating a little hay; at 9:30 a. m. the following day she appeared to have fully recovered.

Case No. 10—No. 54.

A ewe weighing 115 pounds was fed 5½ ozs. between 2:30 p. m. and 3:30 p. m. At 4 p. m. she was sick, breathing through the mouth; respiration, 104; temperature, 103.6. While standing, frequent jerky muscular movements of the whole body took place. At 4:12 p. m. she was down with head and legs moving almost constantly, except during spasms when the legs were stretched out and the head and neck drawn back. The animal died at 4:35 p. m.

Autopsy showed considerable congestion in rumen and fourth stomach; spleen darkened and mushy; kidneys congested; abdominal lymph glands congested; lungs moderately congested.

Case No. 11—No. 58.

A ewe weighing 100 pounds was fed 2 ozs. of the dry leaves at 1:30 p. m. and 2 ozs. more at 2:30 p. m. At 3:20 she was sick; respiration, 70; breathing deep and audible; trembling of the muscles, especially those of the legs. At 3:40 she was down; respiration 30; breathing hard and very audibly through the mouth. She remained down with

head flat on the ground until after 5:10 p. m. At 5:50 p. m. she was up and able to walk, but still quite weak. At 7 p. m. she appeared to have fully recovered.

Case No. 12—No. 61.

A ewe weighing 100 pounds was fed 3 ozs. of air-dried leaves at 7:20 a. m. At 8:30 a. m. she was sick. Down on side with spasms at 9:30 a. m.; respiration, 44; temperature, 103.6. Breathing was mainly through the mouth. At 10 a. m. she was lying quietly on her side, breathing hard and audibly. Died at 10:15 a. m.

Autopsy showed considerable congestion of lungs and a few small hemorrhages of the heart. Other organs presented no gross lesions.

Case No. 13—No. 62.

A ewe weighing 82 pounds was fed 2¼ ozs. of dry arrow-grass leaves at 7:30 a. m. Sick at 8:03 a. m., having a peculiar twitching of the muscles. Down on one side at 8:30 a. m. Frequent spasms occurred.

Figure. 10. Calf dying in convulsions from Arrow-Grass poisoning.

Respiration, 65; temperature, 104.2. At 8:45 a. m. respiration had fallen to 28. Death took place at 9 a. m.

Autopsy showed congestion of lungs and of the fourth stomach. Other organs appeared normal.

Case No. 14—No. 62.

A ewe weighing 82 pounds was fed 4 ozs. of dry leaves, an ounce at a time hourly in order to find out if the poison would be eliminated fast enough so that poisoning symptoms would not develop. The last feeding was at 4:20 p. m. and at 5 p. m. she was sick. The first noticeable symptom was a trembling of the muscles of the legs; respiration, 70. At 5:02 p. m. she was down, breathing through the mouth. She remained in this condition until after 6:30 p. m. At 7:30 p. m. she was up, walking around, but soon fell down again. She was soon on her feet again, but at 7:40 she had another spasm and fell down. At 10:30 p. m. she was up and able to walk around, her gait was very unsteady; the next morning at 7:30 a. m. she appeared to have fully recovered.

Case No. 15—No. 1.

A small yearling calf was fed 8 ozs., of which almost 1 oz. was left uneaten at 9:30 a. m. At 9:50 a. m. he was sick. Most of the time he lay on his side and at frequent intervals he had spasms when his head would be pulled back and legs stretched out. At 10:15 the respiration was 10; and he appeared to be dying. He died at 10:20 a. m.

The autopsy revealed no lesions.

Symptoms of Poisoning.

The first symptom noted was abnormal breathing, usually very rapid, often as high as 150 per minute, in sheep. In other cases it was slow and deep. As symptoms of poisoning developed, the animal breathed quite freely through the mouth, often with the tongue hanging out. This abnormal breathing was often accompanied by trembling or jerking movements of the muscles. In severe cases these jerking movements would develop into spasms or convulsions. After these started the animal would lie on its side panting through the wide-open mouth. From the time the animal went down until partial recovery or death there would be a series of convulsions at short intervals. Several of the animals vomited just before death, drawing part of the regurgitated material into the lungs, which may have hastened death.

Autopsy Findings.

The autopsy findings are few and not characteristic in any way, with the possible exception of congestion of the lungs. Fifty per cent of the cases showed endocardial or epicardial hemorrhages and forty per cent a spleen that was dark and mushy. In general, the blood was darker than normal and formed a clot that was rather soft. The moderate congestion observed in the intestinal tract is of little significance, and, because of the lack of uniformity of the location of the lesion, might be due to other causes. No odor of cyanide was noted in any of the cases; but all the autopsies were made in the open.

If these deaths were due to cyanide poisoning as indicated by the symptoms and chemical findings, the autopsy findings would probably be negligible. Various writers on toxicology consider the post-mortem changes in cyanide poisoning as of little aid in diagnosis. Nunn (Veterinary Toxicology, 1907, p. 130) states: "The post-mortem appearances are nothing characteristic, excepting the pervading smell of almonds from the intestines and in a lesser degree from the whole body." Friedberger and Frohner (Veterinary Pathology, Vol. I, Translation by Hayes, Sixth Edition 1908, p. 236) say: "Autopsy shows bright-red blood in acute cases, brown when chronic; smell of bitter almonds; signs of asphyxia."

Feeding Conditions under which Poisoning by Arrow-Grass Is Likely to Occur.

Few cases of natural poisoning have been observed. In one instance an owner of live stock stated that he had had a number of cows in corral on dry feed for some time. On releasing them they went directly to a patch of arrow-grass which they ate greedily. There was very little grass or sedge in the patch. The poisonous material was therefore but little diluted, and the death of several animals soon followed. The same stockman reported that he was very likely to lose animals when they were fed from a stack of wild-grass hay cut on

meadows containing large quantities of arrow-grass. A sheep owner reported the death of lambs when they fed late in the spring on meadows where arrow-grass was abundant. From the statement it appeared probable that death was due to this plant.

There seems some reason to believe that the plant might cause death in animals which had been on dry feed so long that they would fill up on almost anything green. There appears to be greater danger when the plant is fed dry in hay; the dose required to kill is then far smaller, and there is greater probability that a fatal quantity will be eaten.

Cure of Animals Poisoned with Arrow-Grass.

No experiments were made to determine whether it would be possible to cure a poisoned animal. Apparently there is little hope or prospect of success, because a dose large enough to cause illness is likely to cause death, and because the interval between the time when the first symptoms appear and the fatal result is too short to permit of treatment.

Prevention of Poisoning.

With arrow-grass as with other poisonous plants it appears that not much can be hoped for in the cure of animals already poisoned, but that a good deal can be done to prevent poisoning. Wet meadows, where arrow-grass is very common, should not be cut for hay. However, where the plant is distributed in small clumps rather uniformly and is not very abundant there is little danger. The largest clumps should not be cut, or, if cut, should not be loaded on the wagons and should be burned when dry. Animals should not be put on pastures containing an abundance of arrow-grass when they are very hungry. In some cases, moreover, portions of pastures and meadows where arrow-grass grows in great abundance should be fenced and left unused. By these methods it should be easy to prevent losses due to this poisonous plant.

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THE UNIVERSITY OF NEVADA
AGRICULTURAL EXPERIMENT STATION
S. B. DOTEN, Director

Bulletin No. 99 RENO, NEVADA December, 1920

To diminish suffering and loss among domestic animals

THE NARROW-LEAVED MILKWEED

(*Asclepias Mexicana*)

and

THE BROAD-LEAVED OR SHOWY MILKWEED

(*Asclepias speciosa*)

PLANTS POISONOUS TO LIVE STOCK IN NEVADA

By

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STUDIES OF POISONOUS PLANTS IN THE UNIVERSITY OF NEVADA

In recent years, as the forage on the open public range in Nevada has become more and more depleted, losses of sheep and cattle from poisonous plants have steadily increased. However, even the stockmen and herders themselves do not know fully just which plants are poisonous nor how to avoid them.

The Nevada Agricultural Experiment Station has therefore undertaken a study of the poisonous plants of the sheep and cattle ranges. The experimental work is of a simple character, consisting largely of practical feeding tests. The plants are brought to the University fresh from the ranges and are fed to common range live stock in small corrals. The symptoms of poisoning are recorded; and after the death of the animal the carcass is cut up and the organs are removed and studied.

An attempt is also made to isolate the active poisonous principle of the plant by suitable chemical methods and to determine its chemical nature.

These experiments are showing clearly which range plants are dangerous, what part of the plant is poisonous, and at what season of the year it must be avoided. They are also showing us that many suspected plants are harmless, while others which are considered harmless are in reality deadly.

In all these experiments it is our purpose first to obtain exact information concerning the poisonous range plants and then to spread it far and wide among the stockmen of the West in the hope of diminishing suffering and loss among western sheep and cattle.

S. B. DOTEN,
Director, Nevada Agricultural Experiment Station.

November 1, 1920.

SECTION I

The Milkweeds as Plants Poisonous to Live Stock in Nevada

SUMMARY

(1) There are two common milkweeds in Nevada, both of which are poisonous to sheep and cattle.

(2) One is a slender, erect, branching weed with long, narrow, dark-green leaves, small flowers, and slender pods. The other is a tall and fleshy weed with large, broad, light-green leaves, coarse flowers, and thick rough pods.

(3) Both kinds grow in fairly moist places, along irrigation ditches, by fences and on stream banks, on roadsides, and in patches in damp pastures.

(4) In the autumn the pods break open and release quantities of flat brown seeds, each of which bears a tuft of shining silky hairs, lighter than thistledown. The seeds are carried far by wind and water. Once established, the plant spreads locally by means of its underground stems.

(5) Animals poisoned by the narrow-leaved milkweed become dull and stupid within a few hours. They walk about with a wobbling, unsteady gait, finally losing all control over the muscles of the legs, and falling or lying down. After the animal is down, it has spasms at short intervals in which the legs are extended rigidly. The heart beats at an increasingly rapid rate; the animal pants and grunts. The head is drawn sharply back. The attack may last for twenty-four hours and end with either the death or the recovery of the animal. If it recovers, it will be in a weak and unsteady condition for several days.

(6) Animals poisoned by the broad-leaved or showy milkweed stop eating, grow dull, and lie down; the breathing is irregular, difficult, and grunting. There are no spasms. The breathing becomes more difficult, and the animals dies quietly.

(7) The narrow-leaved milkweed is far more deadly than the broad-leaved or showy species.

(8) Two or three other milkweeds grow in Nevada; but they are neither common enough nor poisonous enough to be of any importance.

(9) When the narrow-leaved milkweed is accidentally cut and cured in hay, it loses its bad flavor, but keeps its deadly character, thus becoming far more dangerous than when fresh and green. Even the dead and dried leaves, left standing in a field from the summer before, are poisonous in midwinter.

(10) It is a costly and difficult matter to get rid of the narrow-leaved milkweed on even a small piece of ground. If a bit of the underground stem is left in the soil, it will soon produce a new plant.

(11) Both of our poisonous milkweeds have so unpleasant a flavor that neither sheep nor cattle will eat them except when they are very hungry and there is practically nothing else in the field for them to eat.

(12) Poisoning may be prevented by keeping hungry animals and animals in poor condition away from milkweed patches, and by stocking pastures lightly enough to keep the animals constantly provided with other food.

Figure 1—Flowers and Pods of the Narrow-Leaved Milkweed.

OUR WESTERN MILKWEEDS

For many years several kinds of milkweed have been looked upon with suspicion or considered poisonous by western stockmen. This opinion was based largely on their own field observations; and little or no experimental work has been done with any of the species except the whorled-leaved milkweed (*Asclepias galioides*). The latter plant has been carefully studied by the Colorado Experiment Station, which was the first of the western stations to show that sheep may be poisoned by this plant when it is eaten either green or dry. (See Bulletins 246 and 255, Colorado Agricultural Experiment Station.) Later, C. D. Marsh and his associates of the Federal Bureau of Plant Industry published the results of their study of the same species. (See Bulletin No. 800, U. S. Department of Agriculture.)

In the spring of 1918 the attention of the Nevada Experiment Station was first called to our local milkweeds as plants dangerous to live stock when several lambs died after eating the tender, juicy young growth of the showy milkweed (Fig. 4). Since that time the Nevada Station has tested the milkweeds by conducting a long series of experiments in which the plants were fed to both sheep and cattle. More work was done with the narrow-leaved milkweed than with any of the others because it seemed to be our most dangerous species. The result of these feeding tests, together with field observations, are presented in this bulletin.

Classes of Live Stock Poisoned and the Extent of Losses in this State and Elsewhere.

Both feeding tests and field observations have shown that the narrow-leaved milkweed (*Asclepias Mexicana*) is poisonous to sheep and cattle. No feedings of any species of milkweed have been made to horses because there seems to be nothing to show that horses have been poisoned by these plants.

Because of the limited time since the milkweeds were recognized as poisonous to live stock in Nevada, the extent of losses cannot be accurately estimated. Further, unless especially large losses take place, they are usually not reported to the Experiment Station. However, because of the widespread distribution of the narrow-leaved milkweed and the ease with which it kills, it is reasonable to assume that losses of live stock, at least in small numbers, are constantly caused by this common poisonous plant.

In other States, notably Colorado, Utah, and New Mexico, it has been proven that the whorled-leaved milkweed has caused the death of many sheep.

Kinds of Milkweed Dangerous to Live Stock in Nevada.

Several kinds of milkweed grow in Nevada but, from the stockman's point of view, the narrow-leaved species is by far the most important. The other kinds will be discussed briefly toward the end of this bulletin. They are: the Showy Leaved Milkweed (*Asclepias speciosa*); the Heart-Leaved Milkweed (*Asclepias cordifolia*); and the Prostrate Milkweed (*Asclepias cryptoceras*). Our experiments seem to show that the heart-leaved and prostrate milkweeds are not poisonous enough or common enough to be dangerous on the range or in pastures in Nevada.

General Description of the Milkweeds.

The milkweeds are usually erect plants, little if at all branched, varying in height from one to several feet. The roots live over from year to year, sending up new stems each season. The flowers are light-colored, white tinged with green or pink; they grow in rounded clusters, each flower stalk arising from the end of the stalk of the cluster.

Figure 2—Pods and Seeds of the Narrow-Leaved Milkweed.

Each flower has five cup-like structures (hoods), inside of which there is a horn.

The flowers fall and are followed by seed pods from one to three inches long which open along one side when dry to allow the seeds to escape. The seeds are reddish-brown and flat; on one end there is

a tuft of long, white, silky hairs by which they are blown about. The roots of the milkweeds are somewhat brittle, whitish and thickened; this is especially true of the showy milkweed (Fig. 4). The growth of the root is mainly horizontal, as is shown in Fig. 5—The Root of the Narrow-Leaved Milkweed. Sometimes, however, the roots penetrate the soil like the roots of alfalfa.

The milkweeds have a milky sap or juice which gives to them their common name and distinguishes them from most other plants. However, a milky sap is found in many other plants, such as the Mexican poppy, the dandelion and its close relatives, the wild lettuce, spurges, and dog-banes. From all these plants having a milky juice, the milkweeds may be distinguished by the following differences: (1) the Mexican poppy is spiny, while the milkweeds are not; (2) the dandelion and its near relatives have no erect stem, while the milkweeds have; (3) the general appearance of the wild lettuce is quite different from the milkweeds and its flower and flower clusters (heads) are like tiny dandelions and not at all like the flower or flower clusters of the milkweed; (4) the spurges (*Euphorbia*) are mostly low, branching plants with small leaves, the two halves of which are different in shape and size; (5) some of the dog-banes might easily be mistaken for the narrow-leaved milkweed, but they branch more freely and tend to be bushy, at least toward the top. Their flowers are not scattered in dense clusters and do not have hoods as in the milkweed. The pods are similar to those of the milkweed but more slender; the seeds are also similar but smaller and not so flattened.

How to Distinguish the Narrow-Leaved Milkweed from the Showy Milkweed.

The showy-leaved milkweed is quite abundant in Nevada, but it is not nearly so poisonous as the milkweed with the long narrow leaves. The two are easily distinguished by the following differences: (1) the narrow-leaved milkweed has several leaves at each joint of the stem, while the shown species has but two; (2) the leaves of the showy milkweed are much broader, from one-third to one-half as broad as they are long; (3) the narrow-leaved milkweed has smooth pods, while the showy species has pods roughened by projections. Figures 3 and 4 show the general appearance and characteristics of these two plants.

Where the Milkweeds Grow.

The milkweeds are widely distributed in Nevada. They require fairly wet soil, and do not grow on the drier parts of the range. They are common along irrigation ditches and streams, along roadsides, and in pastures and washes and idle lands which have not been cultivated for a number of years. In such locations the narrow-leaved kind is more abundant. It has a wider distribution than the showy milkweed or any of the other species found in this State.

The milkweeds usually grow in full sunlight, although they may be found in partly shaded places as in orchards and among willows and cottonwoods along streams.

In several places in Nevada the narrow-leaved milkweed has been reported to be getting more abundant. Especially is this true along the banks of irrigation ditches. Wherever irrigation systems have been extended to new ground, this poisonous weed soon grows abundantly along the ditch banks.

Figure 3—The Narrow-Leaved Milkweed.

Figure 4—The Broad-Leaved or Showy Milkweed.

All our observations indicate that after it is once established the narrow-leaved milkweed tends to remain confined to the ditch banks and adjoining moist areas. There seems to be little danger of its establishing itself throughout the alfalfa fields and meadow hay lands to such an extent that it would cause the hay to be discriminated against for feeding purposes.

How the Milkweeds Spread.

The milkweeds produce quantities of flat brown seeds, each of which bears a tuft of shining silky hair by means of which it floats on the wind and is carried to considerable distances. Often they are blown into irrigation ditches and carried to distant fields by the water.

New patches may start from seeds, or from pieces of roots carried by plows and other farm implements or picked up by the water and transported to new areas.

Where the plant has become established, the size of the patch is usually increased by the shallow horizontal underground stems which give rise to new plants.

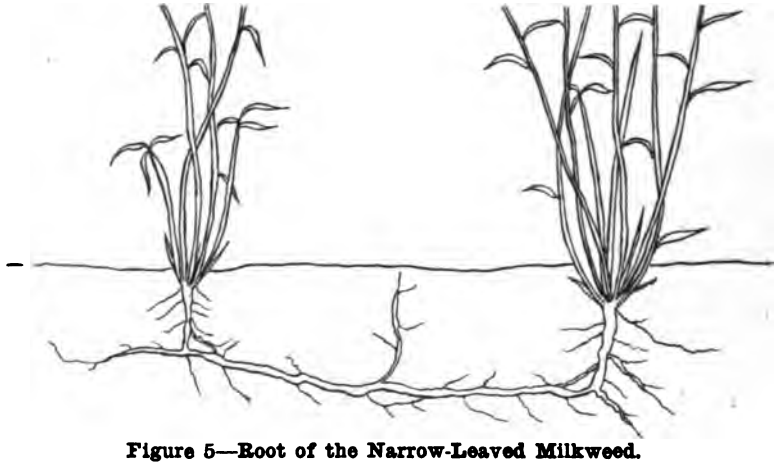

Figure 5—Root of the Narrow-Leaved Milkweed.

It is not uncommon for the same root system to connect up a large number of plants, all of which were produced by the spreading horizontal roots of a mother plant. Thus when it once becomes established it is indeed hard to get rid of this poisonous weed because of the budding of the roots. In some of the milkweeds such buds are known to form as much as two feet below the surface of the ground; and a two-inch piece of the root of the common milkweed was found by A. S. Hitchcock in Kansas to be able to form a new plant. On small areas in Nevada the narrow-leaved milkweed has been dug and pulled two or three times during the season without completely eradicating the plant, because of its ability to produce new plants from small pieces of root left in the soil. Thus any means by which the root is broken up into small pieces and left in the ground will enable the plant to maintain itself and in some instances actually to increase.

THE NARROW-LEAVED MILKWEED (Asclepias Mexicana)

The Part of the Plant Which Is Poisonous.

In our experiments we have fed the whole top of the plant, stems, leaves, and sometimes flowers and seed pods. A few feedings were made of leaves only, and these few tests seem to indicate that the leaves are the most poisonous part of the plant. The pods appear to be less poisonous than either the leaves or the stem. Feeding of seeds alone produced no symptoms. This indicates that the plant is not more dangerous, but perhaps less so, when it is full of seed pods than at other times. For all practical purposes the entire plant may be considered poisonous.

The Time of the Year When It Is Poisonous.

So far as known the narrow-leaved milkweed is poisonous at all stages of growth. Our tests showed it to be poisonous when fed (1) in a green condition, (2) after being cut and dried as hay, and (3) as it dries naturally in the field in the fall. Thus in all stages it is poisonous; and hay containing any large amount of this plant may be regarded as extremely dangerous.

Amount Necessary to Make Sick or to Kill.

We fed the narrow-leaved milkweed to cattle and sheep, (1) in a fresh green state, (2) after being cut and dried, and (3) as it cured naturally on the stems in the fall, (4) the pods alone, and (5) the seeds alone.

TABLE I

The Narrow-Leaved Milkweed—The Fresh Green Plant Fed to Sheep

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms observed	Time of death or recovery	Final result
2	120	5-31-18	2:25 p. m.	½			Negative
28	63	5-31-18	2:30 p. m.	½			Negative
18	95	6- 8-18	4:00 p. m.	½			Negative
25	93	6- 8-18	4:05 p. m.	½	6- 9—7:15 a. m.	6- 9—6:00 p. m.	Recovery
74	98	8-12-20	4:05 p. m.	½			Negative
75	90	8-12-20	4:10 p. m.	½			Negative
78	87	8-12-20	4:15 p. m.	¾	8-13—7:00 a. m.	8-15—8:00 a. m.	Recovery
72	93	8-12-20	4:40 p. m.	¾	8-13—8:00 a. m.	8-14—8:00 a. m.	Recovery
19	68	5-29-18	4:10 p. m.	1	5-30—9:00 a. m.	5-31—8:30 a. m.	Recovery
8	72	5-31-18	2:40 p. m.	1	6- 1—9:00 a. m.	6- 2—9:00 a. m.	Recovery
79	95	8-11-20	4:10 p. m.	1	8-12—8:00 a. m.	8-13—7:00 a. m.	Recovery
8	100	8-12-20	4:20 p. m.	1	8-13—5:00 p. m.	8-14—8:00 a. m.	Recovery
6	65	5-31-18	2:45 p. m.	1½	6- 1—8:00 a. m.	6- 1—4:45 p. m.	Death
77	88	8-12-20	4:30 p. m.	1½	8-13—7:00 a. m.	8-15—8:00 p. m.	Recovery
17	61	5-29-18	4:10 p. m.	2	6:00 p. m.	Before 9:00 p. m	Death

The animals were not watched during the night, usually the first observation being made at 8 o'clock in the morning. This is the reason why, in this and the following tables, under the caption Time of Death or Recovery, "8: 00 a. m." appears so often. It records the condition of the animal at the first observation made in the morning.

The tests summarized in this table indicate that (1) if common range ewes eat one-half pound or less no serious trouble will follow; (2) amounts in excess of one-half pound and up to 1½ pounds will usually make the animal sick, but it will recover; (3) amounts of 1½ pounds or more are quite likely to cause death.

Figure 6—Sheep Poisoned by Narrow-Leaved Milkweed.

Figure 7—Sheep Poisoned by Narrow-Leaved Milkweed.

TABLE II

The Narrow-Leaved Milkweed—The Air-Dried Plant Fed to Sheep

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, ozs.	Time symptoms observed	Time of death or recovery	Final result
56	111	10-17-19	8:20 a. m.	3	----------	----------	Negative
37	90	10-17-19	10:30 a. m.	3	----------	----------	Negative
59	100	10-17-19	8:40 a. m.	4	10-18—8:00 a. m.	10-23—8:00 a. m.	Recovery
58	111	10-21-19	11:30 a. m.	4	----------	----------	Negative
55	112	10-17-19	11:45 a. m.	5	10-18—8:00 a. m.	10-19—8:00 a. m.	Recovery
57	112	10-21-19	11:00 a. m.	5	10-22—8:00 a. m.	10-24—8:00 a. m.	Recovery
46	80	10-20-18	9:30 a. m.	5	10-20—2:00 p. m.	10-23—8:00 a. m.	Recovery
8	100	8-24-20	2:50 a. m.	6	8-25—8:00 a. m.	8-26—8:00 a. m.	Recovery
72	85	8-25-20	2:20 a. m.	7	Not observed	8-26—8:00 a. m.	Death
45	85	11-26-18	10:00 a. m.	8	11-20—2:00 p. m.	11-21—2:45 p. m.	Death

After the green plant has been thoroughly dried in the sun it loses approximately 65% (two-thirds) of its original weight. Its condition is then much the same as it would be if cut and cured in hay. In the feeding tests the air-dried material was in most instances mixed with alfalfa hay and fed.

The feedings of hay and milkweed may be briefly summed up for range ewes as follows: (1) 3 ounces may or may not make the animal sick, (2) 4 to 6 ounces will usually produce poisoning, (3) amounts in excess of 6 ounces will probably cause death.

The dried milkweed is evidently very poisonous. While the plant is green sheep are very likely to avoid it because the taste is repellent; but after it is dry it loses much of its bad flavor and is then more dangerous because more readily eaten.

It takes about three parts of fresh milkweed to make one part of air-dried; and it is an interesting fact that if the above amounts of air-dried material are multiplied by 3 to give the original green weight they agree very closely in most cases with the results of Table I.

The feeding tests given in Table II therefore indicate that drying causes little if any loss of the poisonous principle. Consequently when this milkweed is cut and fed in hay, it becomes a serious source of danger.

TABLE III

The Narrow-Leaved Milkweed—The Plant Which Had Dried Naturally in the Field Fed to Sheep

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms observed	Time of death or recovery	Final result
48	85	11-12-19	2:30 p. m.	¾			Negative
56	115	11-29-19	1:50 p. m.	½	11-30—8:00 a. m.	12- 2—8:00 a. m.	Recovery
43	80	12- 9-19	9:00 a. m.	¾	12- 9—2:45 p. m.	12-10—8:00 a. m.	Recovery
45	84	12-16-18	10:45 a. m.	¾	12-17—8:00 a. m.	12-18—8:00 a. m.	Recovery
43	80	12-26-18	11:30 a. m.	1	12-27—8:00 a. m.	12-30—8:00 a. m.	Recovery
43	80	1- 2-19	2:00 p. m.	1½	1- 2—9:00 p. m.	1- 3—3:00 p. m.	Death

The plants which were used in the above feeding tests were collected in late autumn after they had fully matured and become dry. The feedings were made in the months of November, December, and January. The results may be summed up briefly as follows: (1) small amounts up to 3 ounces are not dangerous, (2) amounts from 5 to 16 ounces will usually produce poisoning, (3) amounts in excess of 16 ounces are extremely dangerous, and are likely to cause death.

Comparing the results given in Table I with those of Table III, it is found that it takes about as much of the naturally cured material, dry weight, to cause death as of the fresh green plant. From this it appears that some of the poison is destroyed or lost when the dried plant stands exposed to snow and rain after the leaves are dead.

During the fall and winter months the dried plants may be found still standing. Other feed is usually very short and scarce at that time of the year; and the narrow-leaved milkweed, still retaining a considerable part of its original poison, is then a source of danger to grazing animals.

TABLE IV

The Narrow-Leaved Milkweed—Seeds Fed to Sheep

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, ozs.	Time symptoms observed	Time of death or recovery	Final result
58	98	9-7-19	3:30 p. m.	2			Negative
59	101	9-7-19	3:40 p. m.	5			Negative

In late summer and early fall the narrow-leaved milkweed has a large number of seeds and pods. In previous feeding tests the pods and seeds of the showy milkweed were found to be the most poisonous part of the plant; so it was thought that this might also be true of the narrow-leaved milkweed. Two feedings of seeds were made, one of 2 ounces and the other of 5 ounces. Neither animal was poisoned. The quantity of seed which we fed in either test represents the seed production from a large number of plants, a number in excess of what it is believed any animal would be able to get within a reasonable length of time. Consequently it seems that the danger of poisoning from these seeds is very slight and that such poisoning is highly improbable.

Figure 8 — The First Symptoms of Poisoning by Narrow-Leaved Milkweed.

TABLE V

The Narrow-Leaved Milkweed—Green Pods Fed to Sheep

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs	Time symptoms observed	Time of death or recovery	Final result
73	77	8-17-20	4:20 p. m.	½			Negative
74	98	8-17-20	4:35 p. m.	1			Negative
8	100	8-17-20	4:50 p. m.	2			Negative
69	80	8-19-20	7:40 a. m.	2½	8-20—7:00 a. m.	8-22—8:00 a. m.	Recovery
8	100	8-19-20	7:30 a. m.	3½			Negative

Five feedings of green pods were made, using amounts of from one-half to 3½ pounds. None of these feedings caused poisoning with the exception of one 2½-pound feeding. These tests indicate that the pods are less poisonous than the leaves and stems, and that the danger of loss is smaller when the plant is full of pods.

TABLE VI

The Narrow-Leaved Milkweed—The Dried Plant Fed on Successive Days to Sheep

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, ozs.	Time symptoms observed	Time of death or recovery	Final result
37	85	10-21-19	11:45 a. m.	2			Negative
		10-22-19	11:15 a. m.	2			Negative
		10-23-19	10:30 a. m.	2			Negative
		10-24-19	10:00 a. m.	2			Negative
		10-25-19	7:30 a. m.	2			Negative
		10-26-19	11:00 a. m.	2			Negative
		10-27-19	8:30 a. m.	3			Negative
		10-28-19	10:00 a. m.	3			Negative
		10-29-19	10:00 a. m.	4			Negative
		10-31-19	11:30 a. m.	5	11- 2—7:00 a. m.	11- 3—8:00 a. m.	Recovery
Dry material collected September 6. Sheep never very sick.							
59	93	10-27-19	11:10 a. m.	2			Negative
		10-28-19	8:30 a. m.	2			Negative
		10-29-19	11:00 a. m.	4			Negative
		10-31-19	10:30 a. m.	4	10-31—2:00 p. m.	11- 2—7:30 a. m.	Recovery
Dry material collected September 6. Sheep only slightly sick.							

TABLE VI—*Continued*

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, ozs.	Time symptoms observed	Time of death or recovery	Final result
59	90	11- 3-19	10:30 a. m.	6	11- 3—5:00 p. m.	11- 6—8:00 a. m.	Recovery
		11- 8-19	11:30 a. m.	7	11- 9—7:00 a. m.	11-10—8:00 a. m.	Recovery
		11-12-19	2:00 p. m.	6	11-15 (dull)	11-15—8:00 a. m.	Recovery
Material collected as it had dried in the field. Sheep quite sick.							
10a	100	7-21-19	9:00 a. m.	2			
		7-22-19	10:25 a. m.	2	7-22—12 m.	7-23—10:00 a. m.	Death
120	95	7-21-19	9:30 a. m.	2			
		7-22-19	10:25 a. m.	2			Negative

When animals are poisoned with the narrow-leaved milkweed they are affected for a considerable time, the poison appearing to be eliminated slowly. Because of this slow recovery it was thought that small amounts fed daily might cause an accumulation of the poisonous principle in the animal.

Ewe 37 was fed daily 2 ounces of sun-dried milkweed for six days without showing any symptoms of poisoning. The dose was then increased to 3 ounces for two days. On the following day, 4 ounces were fed without causing any symptoms, and two days later she was fed 5 ounces and became only slightly sick. During the ten-day period she had been fed a total of 27 ounces; yet it was only on the last day, when she was fed 5 ounces, that she showed any signs of poisoning. In all the tests summarized in Table II the feedings of 5 ounces produced symptoms of poisoning. These successive feeding tests of Table VI indicate very clearly that there is little if any cumulative action when the milkweed is fed at brief intervals.

Sheep 59, which had been made very sick with 4 ounces in an earlier experiment, was fed 2 ounces daily for two days; then 4 ounces were fed without producing any symptoms. Two days later, when again fed 4 ounces, this animal was made slightly sick. This feeding test also indicates that there is no cumulative action when small doses are fed on consecutive days.

Three days later, on November 3, Sheep 59, the same animal as mentioned above, was fed 6 ounces of the sun-dried milkweed, which made it quite sick. Five days later it was fed 7 ounces and again it developed symptoms of poisoning. Finally, on November 12, four days later, 7 ounces were fed, the animal again becoming slightly sick. Each of these feedings made the animal sick, but not nearly so sick as the original 4 ounces. The last three feedings were made with a different lot of milkweed material which may have been less poisonous; although when 5 ounces of this lot was fed to another ewe it made her sick for two days.

Animal 10a died when given the second feeding of 2 ounces. This case can hardly be considered as at all typical because the animal was found to have a badly diseased kidney which may have retarded the elimination of the poison and hastened death.

Sheep 120, when fed the same amounts and in a similar way as Sheep 10a, developed no poisoning symptoms and to all outward appearances was normal.

These tests prove rather clearly that there is no cumulative action of the poisonous principle in sheep. The same, it is believed, will hold true for other animals. Rather, they seem to show that there is a

tendency to develop tolerance for the poison. It may be that the slow recovery is due more to the slowness with which the nervous system recovers from the action of the poison than to the poison being retained in the system.

TABLE VII

The Narrow-Leaved Milkweed—The Green Plant Fed to Cattle

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms observed	Time of death or recovery	Final result
15	260	8-11-20	8:00 a. m.	1			Negative
19	270	8-14-20	11:10 a. m.	1½			Negative
15	260	8-13-20	4:15 p. m.	2			Negative
19	270	8-16-20	2:50 p. m.	2½	8-17— 7:00 a. m.	8-17—11:40 a. m.	Death
20	320	8-14-20	2:30 p. m.	3	8-15— 8:00 a. m.	8-18— 8:00 a. m.	Recovery
9	225	8- 9-19	10:00 a. m.	3½	8-10— 8:00 a. m.	8-11— 4:00 p. m.	Recovery
888	211	7-23-19	8:30-11:30	4½	7-23— 1:00 p. m.	7-25— 8:00 a. m.	Recovery
7	195	8-12-19	4:00 p. m.	5	8-12—10:00 p. m.	8-13—10:00 a. m.	Death

The foregoing table made from tests with yearling animals may be briefly summarized for a stockman's use as follows: (1) amounts below 2 pounds are not ordinarily dangerous; (2) amounts in excess of 2 pounds and up to 5 pounds are dangerous; (3) amounts of 5 pounds or more may be reasonably certain of causing death; (4) there is a wide variation in the susceptibility of individual animals, some being poisoned with less amounts than others.

TABLE VIII

The Narrow-Leaved Milkweed—The Green Pods Fed to Cattle

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms observed	Time of death or recovery	Final result
15	260	8-16-20	1:45 p. m.	2½			Negative

This one feeding showed very clearly from the view-point of a stockman that there is no increased danger from an animal eating pods, for (1) it takes a large number of the plans to produce 2½ pounds of pods, a greater number than any animal would graze in any one time; and (2) if 2½ pounds produce no symptoms of poisoning, it is plain that the pods are not especially poisonous.

The following table summarizes the feeding of air-dried narrow-leaved milkweed to cattle. This material was cut green and allowed to dry thoroughly in the sun; the weight when dry being approximately 66% less than the green weight:

TABLE IX

The Narrow-Leaved Milkweed—The Air-Dried Plant Fed to Cattle

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms observed	Time of death or recovery	Final result
48	272	9-24-20	10:00 a. m.	¼			Negative
15	260	8-25-20	1:00 p. m.	¼			Negative
49	298	9-15-20	9:00 a. m.	½	9-16—4:30 p. m.	9-17— 8:00 a. m.	Recovery
15	260	6-15-20	8:00 a. m.	½	6-15—2:30 p. m.	6-16— 8:00 a. m.	Recovery
8	225	10-16-19	4-6 p. m.	½	10-17—8:00 a. m.	10-17—11:00 p. m.	Death
17	345	6-16-20	10:00 a. m.	¾	6-17—8:00 a. m.	6-18— 8:00 a. m.	Recovery
18	220	7-21-20	5:00 p. m.	¾	7-22—8:00 a. m.	7-23— 7:00 a. m.	Death
31	280	6-14-20	11:30 a. m.	3	6-14—7:00 p. m.	6-15— 7:00 a. m.	Death

For the practical purposes of the livestock business the following conclusions may be drawn from this table for yearling animals weighing around 250 pounds: (1) small amounts of one-fourth pound or less are practically harmless; (2) amounts of one-half pound are dangerous but not fatal; (3) amounts of three-fourths of a pound will either kill the animal or make it very sick; (4) all amounts in excess of three-fourths of a pound are highly dangerous.

Animal 31, through a mistake, was fed 3 pounds of the dried plant mixed with alfalfa. The animal ate this very greedily. This shows that an animal will readily eat much more than a fatal dose of the dry milkweed, especially if it is mixed with a palatable feed such as alfalfa hay. When the plant is dried, it does not lose its poisonous character, but apparently does lose its bad flavor and becomes much more attractive to both sheep and cattle.

Figure 9—Calf Poisoned by Narrow-Leaved Milkweed.

SYMPTOMS OF MILKWEED POISONING

The first symptom noted in sheep is extreme dullness or entire loss of appetite. In as sluggish an animal as a sheep this abnormal dullness is often difficult to detect, and some of the tests recorded as negative may have had this symptom. In several cases there was a distinct trembling over the entire body accompanied by salivation. The next symptom to appear was a wobbly unsteady gait, first noticeable in the hind legs. In several cases this became worse until the animal staggered and was hardly able to walk, sometimes falling over.

In extreme cases this would be followed by a stage where the animal was down and unable to get up. Some of the animals while down were in a comatose stage as if asleep or in deep stupor.

In the fatal cases there was a series of spasms while the animal was down, much resembling the symptoms of water hemlock (poison parsnip, *Cicuta*) poisoning. While

in this condition the eyes were staring and bleared, the pupils dilated. The head was drawn far back; in many cases there was champing of the jaws and grating of the teeth, with rapid running or kicking movements of both the hind and front legs, followed by spells when the legs would be extended and rigid. Any disturbance of the animal then brought on additional spasms, attended frequently by bleating grunts or groans. In all fatal cases the spasms occurred at irregular intervals until death, spasms becoming weaker and of shorter duration with a longer interval between them.

In nonfatal cases the symptoms during recovery were as follows: If the animal had been down, it would get up but be hardly able to walk, often falling down in its attempt to keep on its feet. As the animal began to get better it would walk with a distinctly unsteady gait and would sometimes refuse to eat for a considerable length of time. Some would eat while still hardly able to walk. The symptoms would disappear so gradually that it would often be very difficult to say definitely when the animals had recovered, just as it was hard to tell when they began to get sick.

The sheep that died were sick from five to twenty-four hours. Those that recovered were sick from twelve to seventy-two hours, most cases from twelve to forty-eight hours. Cattle showed practically the same series of symptoms as did sheep. Those that died were sick twelve to fifteen hours, and those that recovered were sick eighteen to forty-two hours.

Typical Cases

Case No. 1—A sheep weighing 100 pounds was fed 4 ounces of air-dried leaves at 8:40 a. m. on November 17, 1919. The following morning at 8 a. m. she was sick and walked with an unsteady gait. At 2 p. m. she was much worse and was hardly able to get up. By 6 o'clock she was down and unable to rise. She lay flat on her side and appeared to be in a deep stupor until 2 p. m. of the 20th, when she got up, but walked with a very unsteady gait and appeared to have imperfect control of the muscles of one hind leg. She was so weak that she fell down, but soon got up again. Next morning she appeared normal, except that she limped on one hind leg.

Case No. 2—An ewe weighing 115 pounds was fed 5 ounces of air-dried material at 11 a. m. on October 21, 1919. By midnight no symptoms had appeared. At 8 o'clock next morning she was sick and scarcely able to walk. By 11 a. m. she was down and was hardly able to get up. At 9 p. m. she was still sick, and the following day she staggered around when she walked. Next morning, October 23, she appeared to have practically recovered.

Case No. 3—A ewe weighing 85 pounds was fed 8 ounces of dry leaves at 10 a. m. on November 20, 1919. At 2 p. m. she was drooling freely and not eating. By 4:30 p. m. she walked with an unsteady gait, this being especially noticeable in the hind quarters. She continued to get worse, and at 7:30 p. m. could hardly get up, and when upon her feet could walk only a very few steps before she would fall down. By 9:30 p. m. she was unable to stand. Next morning at 8 o'clock she was about the same as when seen at 9:30 the night before. She made several attempts to get up, but each time would fall over. Over the entire body there was a peculiar trembling of the muscles. At 11 a. m. when-

ever disturbed or moved she went into convulsions. At 2:30 p. m. she had a severe convulsion, and died at 2:45 p. m.

Case No. 4—A ewe weighing 65 pounds was fed 1½ pounds of green material at 2:45 p. m. At 8:40 p. m. she was sick. When she attempted to walk it was with a staggering motion. By 8 o'clock next morning she was down on her side, her head drawn far back, eyes staring and bleared, the pupils dilated. At times she would grind her teeth and champ her jaws. Most of the time there was a rapid running movement of the legs, followed by spells when they would be extended and extremely rigid. This series of movements continued until noon. By 2:30 p. m. the spasms had become weaker and of shorter duration, and the intervals between them were longer. At 3:30 p. m. the spasms were very weak, lasting for an instant or two and recurring about every ten minutes. The animal's temperature was then 105.6°. At 4 p. m. the spasms increased in violence, became more severe and were accompanied by bleating grunts. At 4:15 p. m. there was a severe spasm lasting about five minutes, accompanied by champing of the jaws, grinding of the teeth, and foaming at the mouth. The head was frequently drawn far back. These severe spasms continued about every two minutes until shortly before death, which occurred at 4:45 p. m.

The autopsy showed the spleen slightly mushy, the liver soft and friable; all other organs appeared normal. (Brain not examined.)

Case No. 5—A ewe weighing 80 pounds was fed at 2 p. m. January 2, 1919, 1½ pounds of material that had dried naturally in the field. By 9 a. m. she was sick, walked with an unsteady gait, this being especially noticeable in the hind legs. At 8 a. m. the next day she was down and unable to get up, lying flat on her side with legs stretched out. Frequently she would chew at the bedding, and would champ her jaws most of the time. A peculiar trembling of the nose and lips was noticeable. At 9:30 p. m. she was in the same condition, groaning as if in pain, kicking the hind legs and frothing at the mouth. Her temperature at 1:30 p. m. was 103°. She was in this condition until 3 p. m., when she died.

Case No. 6—A sheep weighing 100 pounds was fed 2 ounces at 9 a. m. July 21. The next day at 10 a. m. 2 ounces more were fed. By noon the animal was sick, walking with an unsteady gait. It continued to get worse during the afternoon. Next morning it was unable to get up and had convulsions when disturbed. It soon fell over on its side and had running movements with its legs. It remained in this condition until death, which took place about 10 a. m.

The autopsy at 11 a. m. showed the following conditions: There was an acute cloudy swelling of the right kidney. The left was affected by a chronic disease not caused by poisoning. The liver was friable and highly reddened; blood flowed from cut surface. Some of the lymph glands were hemorrhagic. The brain showed marked congestion of the meninges, especially over the cerebellum and the anterior portions of the cerebrum. Many minute pin-point hemorrhages were found in the gray matter of the brain. These were located in the corpus striatum, corpus callosum, medulla, and medullary portions of the cerebrum.

Case No. 7—A sheep was fed 7 ounces of dry material at 2:30 p. m.,

August 25, 1920. It was found dead next morning at 8 o'clock. The autopsy showed the following: carcass bloated, pupils dilated. There was considerable congestion of the mucous membrane of the fourth stomach (abomasum) and small pin-point hemorrhages in the duodenum. The mucous membrane of the bladder was congested. There was a cloudy swelling of the kidneys. In the brain there was marked congestion of the pia mater, and marked injection of the capillaries of the medulla. Hemorrhages were found in the gray matter of the brain.

Case No. 8—A yearling calf weighing 211 pounds was fed 4¼ pounds of fresh material on July 23, 1919, between 8:30 and 11:30 a. m. At 1 p. m. it was frothing at the mouth, and its breathing was rapid and irregular. These symptoms (perhaps not due to the milkweed) soon disappeared and the animal seemed normal the rest of the day. The next morning it walked with a peculiar, stiff staggering gait. It ate a little when fed. At 6 p. m. it was very weak and wobbly, much more so than in the morning. At 8 a. m. the next day it was much better, but still walked with a stiff unsteady gait.

Figure 10—An Early Stage of Poisoning by Narrow-Leaved Milkweed.

Case No. 9—A yearling calf weighing 225 pounds was fed 3½ pounds of green material at 10 a. m. on August 9, 1919. At 8 a. m. the next day it was sick and hardly able to get up. When on its feet it was very weak and staggered about. At noon it appeared to be in about the same condition as in the morning. By evening it was much better. Next morning at 8 a. m. it appeared to have quite completely recovered, but at times later in the day it staggered somewhat in walking.

Case No. 10—A yearling calf (195 pounds) was fed 5 pounds of green material at 4 p. m. on August 12, 1919. At 10 p. m. it was slightly sick. Next morning at 8 o'clock it was very sick and hardly able to walk, staggering and falling down frequently. Finally it collapsed and lay on its side, kicking rapidly with its legs. Death occurred at 10 a. m.

In the autopsy slight congestion was found in the fourth stomach and in the meninges of the brain.

Case No. 11—A yearling calf weighing 255 pounds was fed on October 16, 1919, between 4 and 6 p. m., three-fourths of a pound of dry material, which was collected September 6 and air-dried. At 8 a. m. next day it was sick and hardly able to walk. There was marked incoordination of the muscles of the hind legs. At 2 p. m. it was down on its side, with legs stretched out, head drawn far back, eyes rolled up; the animal appeared to be dying. This was followed by periods when it seemed to be getting better, but soon it would have another similar attack. During the afternoon it had a series of such attacks. At 8 p. m. it was still down and unable to get up. At midnight it was found

dead. The autopsy at 9 a. m. October 18 showed slight hemorrhages in the trachea, lungs hemorrhagic, kidneys congested; the heart had severe hemorrhages, both internally and externally.

Case No. 12—A yearling calf weighing 220 pounds was fed three-fourths of a pound of dry leaves at 5 p. m. July 21, 1920, which was all eaten next morning. At 8 a. m. the animal was sick and walked with an unsteady gait. The incoordination was most marked in the hind legs, especially the left hind leg. The back was curved to the right. It kept getting worse during the afternoon, and was found dead next day at 7 a. m. The autopsy at 9 a. m. showed the lymph glands hemorrhagic. There was acute inflammation of the liver and of the bladder. Small hemorrhages were found on the heart. The meninges of the brain were congested in region of the cerebrum. There were minute pin-point hemorrhages in the gray matter of the brain; these were more marked in the left side than in the right. These hemorrhages were located in the corpus striatum and in the medullary portion of the cerebrum and cerebellum.

The Time of the Year When Milkweed Is Poisonous.

All the feeding tests and field observations clearly indicate that this milkweed is poisonous at all times of the year. Animals have been poisoned and killed by plants collected in the spring of the year when they were just a few inches high, and by plants collected at later stages of growth up to the time when they had become fully matured and dried up in the fall of the year. Losses, therefore, may occur at any time when hungry animals feed upon this milkweed.

Prevention of Losses.

There is no known remedy for an animal badly poisoned with this plant. Consequently, to avoid losses it is necessary to understand the conditions under which an animal is most likely to eat a fatal dose. The fresh green milkweed as it grows in the field is not relished by any class of live stock and is eaten only under stress of hunger. This is not the case when it is cut and dried and put up in hay, for it then loses a large part of its disagreeable taste and is quite readily eaten. Thus hay containing this milkweed is always dangerous. On the other hand, ranges or pastures where this plant grows are not always dangerous, providing there is enough grass or other forage to satisfy the animals. Thus the losses occur (1) when hungry animals are being herded along driveways or trails where there is little or no feed for stock; (2) when stock are pastured on overgrazed or very closely grazed ranges supporting this plant; (3) when stock are held in pastures growing this milkweed until all the valuable forage has been eaten; and (4) when stock are bedded on areas where this milkweed is abundant.

Most plants of a poisonous nature contain substances which are distinctly distasteful to live stock. In general it may be said that an animal will first graze plants to which it has been used and whose flavor has been found agreeable. However, in the absence of good grazing it will eat what it is forced to eat in an effort to satisfy its hunger. It has been found that on certain ranges many plants are eaten which on other ranges are but seldom touched by the same class of live stock. Further, it has been observed that an animal in good flesh will not, when hungry, eat offensive plants as readily as poor

hungry animals will. Further, poor half-starved animals are more easily and readily poisoned than when well fed. Thus the condition of the animal determines in a large measure the extent to which it will graze poisonous plants and the probability of serious or fatal poisoning.

THE SHOWY-LEAVED MILKWEED AND OTHERS AS POISONOUS PLANTS

After two years of observation in the field and in the feeding corrals we have good reason to believe that the narrow-leaved milkweed is of far greater importance as a poisonous plant than any other species of milkweed growing in Nevada. For that reason only a few experiments with the other milkweeds have been made at this Station. The following discussion of the other species found in Nevada will give a general idea of their appearance and poisonous properties:

The Showy Milkweed (Asclepias speciosa).

This species of milkweed can be found in many parts of Nevada, but it does not seem to be very abundant anywhere. It requires about the same conditions for growth as does the narrow-leaved milkweed, and they are often found growing together.

Live stock do not like it, and it is eaten only under stress of hunger. Often fields grazed by cattle may be closely cropped, with this milkweed standing untouched.

As a poisonous plant it seems to be much less important than the narrow-leaved milkweed. Figure 4 shows the general appearance of this plant growing in the field.

Feeding experiments were made with (1) the green leaves, (2) the leaves as they had dried up naturally in the field, (3) the seeds, and (4) the pods.

TABLE X

The Showy-Leaved Milkweed—Green Leaves, Pods, Seeds, and Dried Leaves Fed to Sheep

Animal No.	Weight, lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms observed	Time of death or recovery	Final result	Part of plant fed
42	106	9-10	10:00 a. m.	1	----------	----------	Negative	Green leaves
84	103	9-11	9:00 a. m.	1½	----------	----------	Negative	Green leaves
64	99	9-12	10:00 a. m.	2	----------	----------	Negative	Green leaves
100	102	9-14	2:00 p. m.	2	----------	----------	Negative	Green leaves
24	85	9- 6	2:30 p. m.	2½	9-7—3:00 a. m.	9-10—8:00 a. m.	Recovery	Green leaves
33	94	9- 6	11:30 a. m.	2½	9-6—6:00 p. m.	7- 7—8:00 a. m.	Death	Pods
27	81	9-12	4:00 p. m.	½	9-7—7:00 p. m.	Before 10:00 p. m.	Death	Seeds
46	80	12-16	11:30 a. m.	½	----------	----------	Negative	Leaves dried in the field
46	80	12-28	10:00 a. m.	1	----------	----------	Negative	

The above feedings seem to show that (1) the green leaves are poisonous, (2) relatively large amounts are required to cause poisonous symptoms in a mature range ewe, (3) the pods alone are poisonous, (4) the seeds are highly poisonous, and (5) the plant dried naturally in the field contains little of its original poisonous matter.

Lambs have been fatally poisoned by grazing upon the tender growth

of this plant in the early spring months when all feed was scarce, but the recorded losses have not been large.

Symptoms of Poisoning by the Showy Milkweed.

The symptoms of poisoning were quite different from those produced by the narrow-leaved milkweed. The first symptom noted was extreme dullness, with a total loss of appetite and a tendency to lie down. In the severe cases the breathing was distinctly irregular, the breath being expelled with a grunt. Spasms were entirely absent and in the whole series symptoms seemed much unlike those produced by the narrow-leaved milkweed.

Typical Cases

Case No. 1—On September 6, 1918, at 2 p. m. a yearling range lamb weighing 85 pounds was fed 2¼ pounds of the fresh green leaves. At 8 a. m. the next day it showed symptoms of poisoning. During the day of September 9 it was still sick. September 10 it appeared to have recovered.

Case No. 2—September 6, 1918, at 11:30 a. m. a ewe weighing 94 pounds was fed 2¼ pounds of green pods. She was sick by 6 p. m. the same day. At 9:30 she was down; the breathing was labored and grunting. No other symptoms were exhibited. The next morning at 8 a. m. she was found dead.

Case No. 3—September 12, 1918, at 4 p. m. a yearling lamb weighing 81 pounds was fed one-half pound of seeds. At 7 p. m. of the same day it was extremely dull, respiration irregular. At 8:30 p. m. it was much worse; the breathing was more labored and each breath was made with a peculiar grunt. At 10 p. m. the animal was dead.

Heart-Leaved Milkweed (Asclepias cordifolia).

This plant is not abundantly distributed in the fields or ranges of Nevada. It occurs only in the mountain valleys, and does not appear to be poisonous.

Five feedings of this milkweed were made to sheep, the amounts fed ranging from one-half pound to 2¾ pounds. None of the feedings so far as could be observed had any poisonous effect upon the animal.

This milkweed can be distinguished from the showy milkweed by its surface being smooth or free from hairs, while the showy milkweed is covered with fine hairs. The base of the leaf is heart-shaped, which is not the case with the showy milkweed. There is little danger of confusing it with the narrow-leaved milkweed.

Prostrate Milkweed (Asclepias cryptoceras).

This species of milkweed is not important as a poisonous plant. It grows sparingly and is not widely distributed. It is a plant with somewhat tough leathery leaves, and its growth habit tends to be close to the ground. It may be disregarded as a poisonous plant of any importance in Nevada. One feeding of 3 pounds at one time was made to a mature sheep which did not seem to be at all injured by this large amount.

SECTION II

Technical Information Concerning the Narrow-Leaved Milkweed

This section is not intended for use by farmers and stockmen:

The facts included are for the information of chemists and veterinarians.

SYMPTOMS

The appearance of symptoms of poisoning in sheep by *Asclepias Mexicana* occurred about five to seven hours after artificial or natural feeding of the leaves or whole plant.

Five ounces of the dried plant appeared to be the minimum quantity producing symptoms of poisoning in sheep. Three pounds of the dried leaves appeared to be the minimum quantity producing toxic symptoms in a 250-pound calf, with subsequent recovery.

The first noticeable symptoms in either cattle or sheep are general depression, refusal to eat, and unsteady wobbly gait. The unsteady gait is due to partial paralysis of the hind limbs. Occasionally the paralysis is confined to only one limb. This causes an incoordination in movement, and the animal sways from side to side. Marked muscular trembling is sometimes observed, and in a few hours the animal lies down, refusing to arise. During the period of recumbency tetanic spasms (rigid extension) of the limbs occur at intervals of two or three minutes.

There is no perceptible elevation of temperature. The pulse rate increases with the duration of the attack and shortly before death may attain the rate of 180 per minute, becoming very thready. Breathing is labored and rapid. The head is extended backward and quite rigid. The attack may persist for twenty-four hours, and immediately before death the animal lies in a semicomatose state. In case affected animals recover, the gait is unsteady for two or three days. In some cases incoordinate movements of the hind limbs persist as long as one week after the other symptoms have disappeared.

POST-MORTEM LESIONS

These are not especially characteristic.

Summarizing the observations of post-mortem lesions in sheep and cattle, the following pathological changes were fairly constant in deaths due to ingestion of *Asclepias Mexicana:*

The liver exhibited passive congestion and low-grade cloudy swelling. Kidneys light in color with low-grade cloudy swelling. The mucosa of the abomasum may exhibit congestion of a moderate degree which may be continuous throughout the small intestine. Occasionally marked arborization of the blood-vessels of small intestines is observed.

Occasional subepicardial petechial hemorrhages are observed along the coronary vessels and auriculo-ventricular border. The heart muscle is pale and friable.

The pia mater in cerebral and cerebellar regions exhibited a marked congestion on cut surfaces; minute capillary hemorrhages were observed in the medullary portion of the cerebrum and cerebellum, also in the cropus striatum. The lateral ventricles contained a moderate amount of sero-sanguinous fluid.

Histopathological examination of selected tissues confirmed the observations made at the autopsy. In the brain the hemorrhages were largely from the minute capillary vessels. Occasional interstitial capillary hemorrhages were observed in the reticular tissue between the convolutions of the cerebrum.

The liver exhibited acute parenchymatous hepatitis with passive congestion. The kidneys exhibited low-grade parenchymatous nephritis. Myocardium, acute myositis.

THE ACTIVE PRINCIPLE OF ASCLEPIAS MEXICANA

Several species of *Asclepias* which are physiologically active have been examined chemically, and, from the work done by various experimenters on those investigated, the compounds to which the physiological activity of the plant may be ascribed apparently varies considerably. Glucosides have been found in several species, which act on the animal organism as an emetic. In another species (*syriaca*) a crystalline resinous substance was found which acted as an anodyne and cathartic. Quackenbush reports finding a crystalline glucoside in *Asclepias tuberosa* and *Asclepias cornuti*. March, Clawson, Couch, and Eggleston (U. S. D. A., Bul. 800) have recently reported preliminary experiments on *Asclepias galioides*, a species closely related to *A. Mexicana*, in which they found evidence of the presence of toxic compounds having narcotic properties and also those producing a spasmodic type of intoxication. The active principles were not isolated, but experiments on small animals indicated the presence of toxic material in successive extracts of the dry plant, and gave some idea of the solubility relations of these materials. They found that petroleum ether removed no active material, but that benzol extracted substances which were toxic and produced effects in test animals similar to those observed in poisoning of sheep by the plant. Ether and chloroform extracts from the material already treated with benzol and petroleum ether also were toxic, indicating the possible presence of more than one active principle. Other solvents failed to remove toxic matter from the residue. Evidence of the presence of a minute quantity of alkaloids was obtained; volatile poisons and saponins were not found. Alcohol alone was found to extract all of the toxic material, a part of which was soluble in water producing narcosis, and the part insoluble in water producing poisoning with symptoms typical of range poisoning.

A portion of the material used in our feeding experiments was examined, and results were obtained which were in some ways similar to those reported on *Asclepias galioides*.

A small quantity of the plant was extracted successively with solvents and the amounts extracted by each were as follows:

Benzol	10.55%
Ether	0.64%
Chloroform	0.70%
Ethyl acetate	2.68%
Alcohol	0.46%

Each of the residues from these extractions were administered to guinea pigs by mouth in amounts corresponding in each case to five grams of the dry plant, and all appeared to be nontoxic, except the benzol extract. Thus benzol is capable of removing all of the toxic substances. No reactions were noted in the cases of the materials extracted by the other solvents, the animals appearing normal.

Another small portion of the dry powder was studied by extracting with dilute acid and testing with the general alkaloidal reagents. With each reagent used, indication was obtained of the presence of alka-

loids. No alkaloidal preparations were made for animal experiments. A larger portion of the plant which had been dried was extracted with alcohol by percolation. The alcohol was then removed, and the remaining sirup was evaporated to dryness and extracted repeatedly with boiling water. The aqueous extract so obtained was clear and of a dark-brown color. It had a very sweet taste with a slightly bitter after-taste. The residue from this extraction was a black resinous mass.

The aqueous extract and black residue were administered to a guinea pig by mouth. The amounts given corresponded to 5 grams of the dried plant in each case. The aqueous extract proved to be nontoxic, the animal remaining normal, but the black residue was fatal in three hours. The symptoms exhibited by this animal were the same as those shown by the one to which was given the benzol extract. Apparently, then, the active material of *Asclepias Mexicana* differs from that found in *Asclepias galioides* by Marsh, Clawson, Couch, and Eggleston in that the substance producing narcosis found by them in *Asclepias galioides* is lacking in this plant. It is possible, however, that with doses representing larger quantities of the plant the narcotic effect might be present and more noticeable.

THE UNIVERSITY OF NEVADA
AGRICULTURAL EXPERIMENT STATION

Bulletin No. 101 RENO, NEVADA February, 1921

To diminish suffering and loss among domestic animals

DEATH CAMAS

(*Zygadenus paniculatus* and *Zygadenus venenosus*)

Plants Poisonous to Sheep and Cattle

By

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STUDIES OF POISONOUS RANGE PLANTS IN THE UNIVERSITY OF NEVADA

In undertaking the study of poisonous range plants, the Nevada Agricultural Experiment Station has planned a series of experiments to obtain information upon the following points: (1) the part of the plant which is poisonous, (2) the time of the year when it is dangerous, (3) the kinds of live stock poisoned, (4) the amount which must be eaten in order to cause illness or death, (5) the symptoms shown by the poisoned animals, (6) the conditions under which poisoning occurs, (7) methods of cure and treatment, (8) and methods of preventing poisoning.

In addition, studies are made of the post-mortem conditions shown by the poisoned animal, and of the chemical nature of the poisonous element found in the plant.

The basis of all these experiments consists of long series of feeding tests in which plants are brought fresh from the ranges to the University and are fed to range animals in pens where they are kept under close observation.

This bulletin is a report of the results obtained by feeding the plant known as death camas to range sheep and cattle.

S. B. DOTEN,
Director, Nevada Agricultural Experiment Station.

UNIVERSITY OF NEVADA,
Reno, Nevada, January, 1921.

SECTION I

DEATH CAMAS

Zygadenus paniculatus and *Zygadenus venenosus*

PLANTS POISONOUS TO SHEEP AND CATTLE

SUMMARY

Death camas is a common poisonous plant of the sheep and cattle ranges in Nevada.

It is a low-growing bright-green plant related to the lilies and the onions. It comes up in the very early spring from a bulb buried eight inches or more in the ground. The bulb is much like an onion, but it has no onion odor, and is covered with a thin black coating. The leaves are long, slender, and grass-like. When the plants come up they look a little like Indian corn; but the leaf is narrower and more fleshy, and it has a distinct ridge or keel on the under side. At first there appears to be no stem; but later a flower stalk is sent up bearing a long cluster of pale yellow flowers.

The first green shoots come up early in the spring before there is grass on the range; and it is at this season that sheep and some cattle are poisoned.

It takes from one-fourth to one-half pound of the leaves to make a range sheep sick when the animal is confined in a pen; it takes a much larger dose, three pounds or more, to kill a sheep under the same conditions. On the range where sheep are driven hard and have no chance to rest and recover, smaller doses are probably often fatal.

On the whole, however, under ordinary range conditions it must be somewhat difficult for even one sheep in a band to obtain a fatal dose of the death camas leaves; and it is probable that many losses thought to have been caused by death camas were in reality caused by some other plant.

Sheep fatally poisoned by death camas froth at the mouth and slobber freely, and occasionally vomit. They grow weak in the hind-legs and stagger when made to walk. Within a few hours they become very dull and weak, standing with head and ears drooping and the back arched. Later, they go down and thereafter rise with difficulty if at all; becoming gradually weaker and usually dying within twenty-four hours from the time of feeding.

Cattle show much the same set of symptoms; but are apt not to froth at the mouth and drool as much as sheep. When in good condition they vomit so freely that they recover within two or three days.

In our experiments we did not succeed in killing any young cattle with death camas. Doses of three-eighths of a pound to two pounds made the animal sick, but caused prompt and profuse vomiting which brought about a fairly rapid recovery. On the range, death probably occurs only when half-starved cattle eat a considerable quantity under conditions where the system is too weak to throw off the poison or where weak animals, driven hard, are poisoned and get no chance to rest and recover.

There is no known remedy for death camas poisoning; and even if an antidote were discovered, it is not likely that it could be used suc-

Figure 1. Foot-Hill Death Camas, the Entire Plant, in Bloom.

cessfully under range conditions. Since poisoning occurs only when weak and hungry animals are turned on to death camas ranges where there is no grass or other green feed, and since ordinarily both sheep and cattle will avoid death camas and eat almost anything else in preference, it is evident that the way to avoid poisoning is to keep half-starved animals off death camas ranges and feed some hay until there is grass; and then let the animals scatter out and browse at will, choosing their own forage.

The plants known as death camas have long been recognized as poisonous, being commonly considered as among the most dangerous plants of our western sheep and cattle ranges. Although discussed in nearly all publications dealing with poisonous plants, there is little if any definite information concerning the quantity required to make an animal sick or to cause death; and not much appears to be known about the classes of live stock poisoned, the conditions under which poisoning is most likely to occur, and methods of preventing losses. The experimental feedings and range observations presented in this bulletin were made for the purpose of obtaining exact information upon these points.

Classes of Live Stock Poisoned.

All of the range observations seem to show that more sheep than cattle or horses are poisoned by death camas. No losses of horses have been recorded by the Nevada Experiment Station; and it seems that cattle have been poisoned only when hungry and in poor condition in the spring of the year. Many of the losses on the open range which have been attributed to death camas may in reality have been caused by other plants not known at the time to be poisonous. In fact, a large number of range observations made by the Station show that the probability of poisoning by this plant is by no means so great as is commonly supposed. This side of the matter will be discussed at length farther on in this bulletin.

Common Names.

Death camas is the name by which these plants are commonly known on the range; but they are also called Mystery Grass, Poison Sego, Poison Onion, Lobelia, and Poison Camas.

In Nevada the most common kinds are the foot-hill death camas (*Zygadenus paniculatus*), and the meadow death camas (*Zygadenus venenosus*). The former grows in the foot-hills among sagebrush and other range browse; the latter is more plentiful in moist, grassy places. The foot-hill form is more common in Nevada, being found on most of the ranges in the northern part of the State.

A Description of Death Camas.

The group of closely-related plants known as death camas were formerly included in the lily family; but this family has recently been broken up by botanists who have placed the death camas in the "bunch-flower family" (*Melanthaceæ*).

The plant is erect, producing from two to eight fully formed grass-like leaves. It springs from a layered bulb set from two to eight inches deep in the soil. The bulbs vary in size according to the age of the plant; but they are commonly from one-half to one and one-fourth inches across and are covered by thin, black, papery coats or layers. The leaves are long, narrow, and curved; varying in length from six

to eighteen inches; they are usually less than one-half inch wide; they look a good deal like coarse grass blades with a projecting ridge like the keel of a boat on the under side. They are much thicker and more juicy than ordinary grass blades.

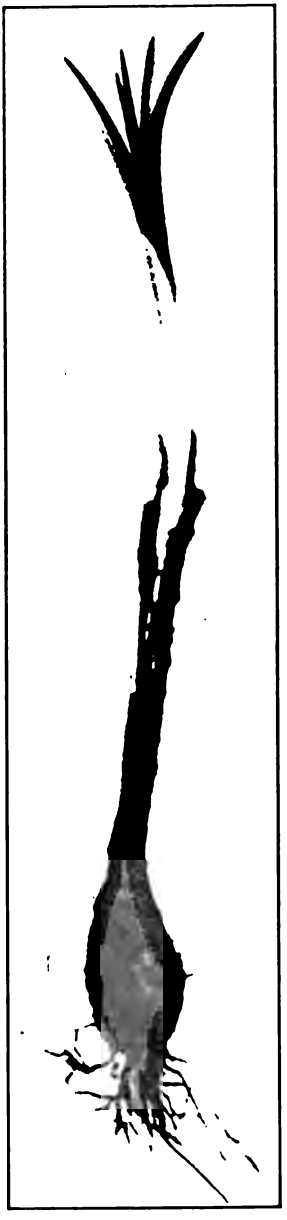

Figure 2. Foot-hill Death Camas, the Young Plant in Early Spring.

There is at first no well-defined stem, the leaves appearing to rise from near the surface of the ground. The flowers are greenish-yellow or whitish, about one-fourth inch across; and are produced in a flower cluster from two to ten inches long. The lower flowers bloom first, and may produce seed pods before the upper flowers bloom. The seeds ripen in the summer; but lie dormant until the next spring, when they sprout and grow into tiny leafy plants. These soon develop small bulbs which may not be any larger than a pea by the end of their first summer's growth. It takes a new plant several seasons to form a bulb sufficiently large to begin to produce flowers and seeds.

The foot-hill death camas differs from the meadow form by having a larger and longer bulb, lying deeper in the soil, usually at a depth of from five to eight inches; while the bulb of the meadow form is smaller and much shorter and is rarely found more than two inches deep in the ground. The foot-hill death camas is also a much larger plant; its flower cluster is branched at the base, while the much shorter cluster of the meadow form is unbranched.

Plants Commonly Mistaken for Death Camas.

Death camas is most commonly confused with the wild onion, although it has no onion odor. When in bloom the two are easily distinguished, for all of the flowers of the onion cluster grow out from the tip of the flower stem, while the flowers of the death camas grow along the sides of the stem as in Figure 4.

Where the Death Camas Grows.

Death camas plants may be found on practically every stock range in Nevada, growing more abundantly in the northern half of the State than in the southern. The ground on which the death camas grows is always quite moist in the spring of the year; and the typical grazing types in which they are found

are: (1) sagebrush, (2) grass, (3) semimeadow areas, and (4) typical weed ranges where the vegetation consists largely of showy flowering plants. They do not grow in the shade under standing timber. They are found on practically all of the mountain foot-hills, the high open mountain park areas, and in the sagebrush country of northern and western Nevada.

The Time of Year When Growth Begins.

The time when death camas starts to grow in the spring varies with the season and also with different exposures and different soils; the green shoots are sometimes found as early as the middle of March.

Figure 3. Foot-Hill Death Camas. Plants in various stages of growth, from seedlings to mature plant in bloom.

The plants make their appearance first on sandy soils and on southern exposures. On the dark loamy and clay soils their growth is much retarded; probably because these soils are moist and consequently warm up less readily. If the weather is fairly warm the death camas will begin to grow from ten days to two weeks after the snow melts out in the spring; and the leaves are soon high enough to cause loss. By the latter part of June on the lower ranges, the plant has usually died down.

How the Flavor of Death Camas Affects the Probability of Poisoning.

All species of death camas which grow in Nevada have a bitter flavor and are extremely distasteful to cattle and sheep. In all our feeding

tests it was practically impossible to get either sheep or cattle to eat this plant readily, even after going hungry for two or three days. When a hungry animal was first fed, a few mouthfuls would be eaten; but almost as soon as the plant juices came in contact with the mouth the animal would begin to wrinkle its nose and move its tongue in such a manner as quickly to get rid of what was in its mouth.

In order to get any large number of plants into an animal it was necessary to resort to forced feedings, which consisted mainly in placing the ground leaves so far back in the animal's mouth that it had to swallow what was given it. When this plant, mixed with palatable

Figure 4. Foot-Hill Death Camas (on left) and Wild Onion. Notice the difference in the arrangement of the flowers on the stem. The flowers of death camas are scattered along the sides of the stem; those of wild onion form a round cluster at the end of the stem.

weeds and grasses, was fed to hungry animals they would sort out the grasses and weeds and eat them, avoiding the death camas wherever possible. This shows clearly how sheep and cattle dislike this poisonous plant and try to avoid eating it.

On many of the grazing ranges in the western part of Nevada, sheep have been closely observed while grazing on ground supporting death camas, with weeds, browse, and a scattering stand of grasses. The sheep nibbled weeds and grasses all around the death camas, leaving it almost untouched. Naturally, no losses occurred under these conditions.

On several of these ranges it was noticed that the death camas plants had been grazed by some animal. A study of conditions on near-by ranges, where it was known that there had been no live stock that season, revealed the fact that a number of rodents, common ground squirrels among others, were eating the leaves and digging up the bulbs. Ordinarily, if there had been sheep on these ranges and poisoning had occurred, it would have been seen that the death camas plants had been grazed; and they would have been blamed for the losses.

A series of similar observations were made on Peavine Mountain, near Reno by J. A. Longyear who states that the tops of death camas plants are nibbled rather freely by ground squirrels.

Because of the fact that in the experimental work it took a large quantity of death camas to kill a sheep, a series of feeding tests were made with the most palatable young green weeds and grasses to find out the amount of such plants a range sheep will eat before its hunger is satisfied.

Two yearling lambs in medium condition were fed a mixture of green

Figure 5. Foot-Hill Death Camas. Plants beginning growth in early spring.

Figure 6. The Foot-Hill Death Camas. This plant has been nibbled by ground squirrels.

grasses and weeds. These animals were fed during a series of days all they would eat in the forenoon and afternoon. The average consumption of weeds and grass was four and one-half pounds on each half-day, or nine pounds per day.

Two old ewes weighing 80 and 90 pounds respectively were put to the same test as the lambs; and it was found that on the average each would eat a little over eight pounds daily. These tests probably show quite accurately the quantity of green feed eaten by a range sheep in a single day.

With death camas the experimental feeding tests showed that the smallest amount which will make a sheep sick is between one-fourth pound and one pound. Amounts of one-fourth to two and one-half pounds in each feeding made the sheep sick; but none died from the direct effects of the poisoning. However, two were so weakened that they died later; one from inflammation and ulceration of the fourth

stomach, the other from pneumonia. Quantities of three pounds or more killed the animals in all cases, with the exception of a single sheep which appeared far more resistant to poisoning than the average animal.

When we compare the capacity of a sheep's stomach, approximately four and one-half of green grass and weeds at a single feeding, with the quantity of death camas required to kill, approximately three pounds or more; then it would appear that the sheep would have to graze very largely on death camas in order to secure a fatal dose.

In order to get a clear idea of how thick a stand of death camas there is on the range early in the spring when the danger is greatest, square-rod plots were laid out where death camas (*Zygadenus paniculatus*) appeared most abundant on the foot-hills southwest of Reno. On April 12, 1918, 32 plants, all that grew on one square rod, were cut off at a height of three-quarters inch above the ground. The total weight

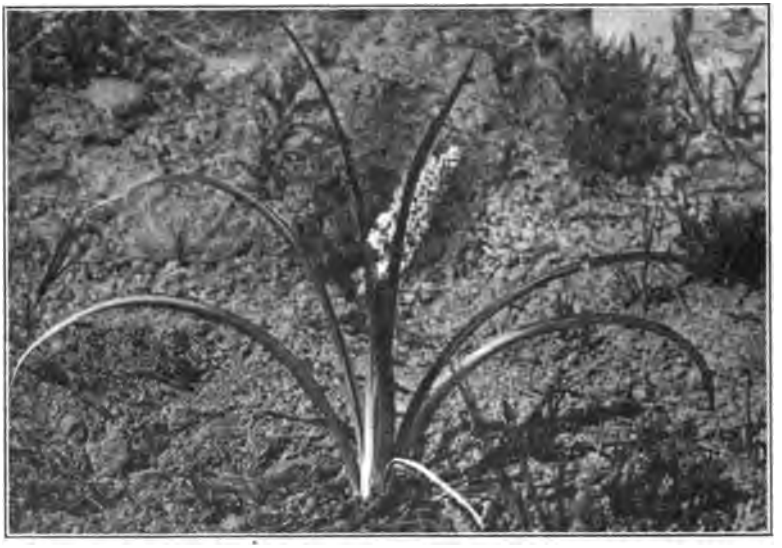

Figure 7. Foot-Hill Death Camas. The leaves appear to spring directly from the ground without any stem.

was 32.8 grams, or a little more than an ounce. On April 15, 52 plants were cut from two square rods and the total weight of leaves cut was 28.6 grams per square rod, or approximately one ounce. At this rate it would take sixteen square rods to produce a single pound of the plant. The leaves at this time were from four to eight inches high.

On all of these plots there was a far heavier stand of death camas than would ordinarily be found on any of the ranges in Nevada. If the plants really grew as thickly on the range as on these selected plots, and if they had reached a height of from four to eight inches, then each acre would produce from 10 to 12 pounds of death camas, enough to poison fatally some three or four sheep. The death camas was cut and weighed at a time of year when all other green vegetation was very scarce, and the likelihood of poisoning was greatest.

On May 17, 1918, when other range vegetation was quite abundant,

17 death camas plants, all that grew on a square rod, were clipped three-fourths of an inch from the surface of the ground; they weighed 4.8 ounces, somewhat more than one-fourth pound. The plants were then in full bloom, some of them going to seed. At this rate and at this time of year an acre would produce approximately 48 pounds of death camas, enough to poison fatally about 16 head of sheep. However, the plant does not grow as thickly as this uniformly over any sheep range. The square-rod plots were selected areas, chosen because they supported an unusual number of plants.

Foot-Hill Death Camas (Zygadenus paniculatus) Feeding Experiments with Sheep.

In the course of the years 1918 and 1919, 69 feedings were made to sheep. Most of these feedings were of leaves, only a few feedings being made of the flower-heads, seed-heads, and bulbs. The results of these feedings are condensed in Table I.

The results of the experiments presented in this table may be summarized as follows:

(1) None of the nine feedings of ⅛ pound each had any appreciable effect upon the animal, indicating that this quantity of the plant is practically harmless; (2) out of the 16 feedings of ¼ pound of the tops, six tests produced no visible symptoms, while 10 made the animals appreciably sick. These feedings show that if sheep in a range flock eat as little death camas as ¼ pound each, trouble may possibly follow.

A single feeding of ¼ pound of the bulbs made one sheep sick, but in a few hours it had completely recovered. It takes several plants to make ¼ pound of the bulbs, more plants in fact than a sheep could possibly ever pull up; so the bulbs as a poisonous part of the plant may be completely disregarded.

(3) Nine out of 12 feedings of ½ pound of the tops produced typical symptoms of poisoning, while three apparently had little effect upon the animals. A half-pound of the tops will generally make a sheep sick; any larger quantity will almost always cause severe poisoning.

(4) Four out of five feedings of ¾ pound each made the animals sick. These sheep were much more seriously affected than those fed ½ pound each.

(5) Of seven feedings of one pound each, six caused severe poisoning while one had no effect. Apparently one pound is as much as any sheep can eat without danger of serious poisoning.

(6) Four feedings of from 1¼ to 1½ pounds all caused severe but not fatal poisoning.

(7) Five feedings of quantities varying between 1¾ pounds and 2½ pounds caused very severe poisoning, resulting in death in two cases.

(8) All feedings of three pounds each resulted fatally. However, sheep No. 18 was twice fed 3½ pounds without a fatal result, although the animal was severely poisoned and was sick for more than a day each time. This animal appeared to be very resistant to poisoning by death camas; later, in tests with other plants, she showed the same resistance to poisoning.

(9) Three feedings of four pounds of the tops all caused death. It seems fair to assume that under ordinary conditions no sheep can eat such a quantity of death camas and live. Still, four pounds is a far greater quantity than any sheep is likely ever to find on the range.

(10) Of three feedings of quantities of seed-heads varying between

TABLE I

FOOT-HILL DEATH CAMAS (*Z. paniculatus*). THE FRESH GREEN PLANT FED TO SHEEP.

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms appeared	Time of death or recovery	Final result
13	69	5-22-18	2:15 p. m.	½			Negative
8	72	5-22-18	2:20 p. m.	½			Negative
6	65	5-22-18	2:25 p. m.	½			Negative
24	67	5-22-18	2:30 p. m.	½			Negative
28	64	6- 4-18	2:15 p. m.	½			Negative
27	70	6- 4-18	2:25 p. m.	½			Negative
26	56	6- 4-18	2:30 p. m.	½			Negative
25	81	5- 6-18	11:10 a. m.	½	2:55 p. m.	5:00 p. m.	Recovery
23	79	5- 6-18	11:30 a. m.	½	3:30 p. m.	5:00 p. m.	Recovery
25	93	5- 9-18	10:20 a. m.	½	2:30 p. m.	5:00 p. m.	Recovery
25	90	5-10-18	9:30 a. m.	½	3:30 p. m.	4:30 p. m.	Recovery
21	96	5-10-18	9:40 a. m.	½			Negative
9	83	5-14-18	11:10 a. m.	½			Negative
7	71	5-22-18	2:35 p. m.	½	7:00 p. m.	5-23—10:00 a. m.	Recovery
17	61	5-22-18	2:40 p. m.	½	8:00 p. m.	5-23— 8:00 p. m.	Recovery
10	82	5-22-18	2:50 p. m.	½	3:55 p. m.	5-23—10:00 a. m.	Recovery
25	93	5-22-18	2:55 p. m.	½	3:55 p. m.	7:00 p. m.	Recovery
25	93	5-24-18	9:10 a. m.	½			Negative
25	93	5-25-18	10:20 a. m.	½	12:00 m.	3:00 p. m.	Recovery
25	93	6- 4-18	2:35 p. m.	½	3:50 p. m.	7:45 p. m.	Recovery
14	116	6- 4-18	2:40 p. m.	½			Negative
26	75	4-17-19	11:45 a. m.	½			Negative
8	72	5- 6-18	11:00 a. m.	½			Negative
20	73	5- 6-18	2:40 p. m.	½			Negative
9	83	5- 9-18	11:45 a. m.	½	6:40 p. m.	5-10— 8:00 a. m.	Recovery
5	77	5-14-18	11:20 a. m.	½	2:30 p. m.	5:00 p. m.	Recovery
8	72	5-15-18	10:40 a. m.	½	1:00 p. m.	5:00 p. m.	Recovery
26	56	5-22-18	3:15 p. m.	½	4:55 p. m.	10:00 p. m.	Recovery
26	56	5-24-18	9:20 a. m.	½	10:50 a. m.	11:50 a. m.	Recovery
26	53	5-25-18	10:30 a. m.	½	2:40 p. m.	3:00 p. m.	Recovery
16	72	5-25-18	10:40 a. m.	½	1:40 p. m.	3:00 p. m.	Recovery
2	120	6- 4-18	2:50 p. m.	½	4:50 p. m.	7:45 p. m.	Recovery
29	75	4-17-19	11:45 a. m.	½			Negative
26	75	4-23-19	11:00 a. m.	½			Negative
46	69	5- 5-19	10:00 a. m.	½	4:45 p. m.	7:00 p. m.	Recovery
11	68	5- 7-18	11:30 a. m.	½			Negative
27	70	5-22-18	3:40 p. m.	½	7:00 p. m.	5-23— 8:00 a. m.	Recovery
27	66	5-23-18	10:35 a. m.	½	1:40 p. m.	8:00 p. m.	Recovery
27	66	5-24-18	9:25 a. m.	½	2:15 p. m.	4:15 p. m.	Recovery
29	75	4-18-19	9:30 a. m.	½	1:30 p. m.	5:00 p. m.	Recovery
28	64	5-24-18	9:30 a. m.	1	2:15 p. m.	4:05 p. m.	Recovery
28	64	5-25-18	10:40 a. m.	1	12:00 m.	8:00 p. m.	Recovery
10	82	5- 9-18	11:35 a. m.	1	1:20 p. m.	9-11— 8:00 a. m.	Recovery
18	94	5-10-18	11:05 a. m.	1	3:30 p. m.	5:00 p. m.	Recovery
23	63	5-22-18	3:50 p. m.	1	7:00 p. m.	5-23— 8:00 a. m.	Recovery
46	70	4-22-19	10:00 a. m.	1	2:40 p. m.	4-23— 8:00 a. m.	Recovery
29	80	4-23-19	10:30 a. m.	1			Negative
12	75	5- 9-18	11:50 a. m.	1½	2:30 p. m.	4:30 p. m.	Recovery
24	67	5-14-18	10:40 a. m.	1½	3:30 p. m.	5:00 p. m.	Recovery
19	68	5- 9-18	10:40 a. m.	1½	1:20 p. m.	6:40 p. m.	Recovery
20	73	5-10-18	11:35 a. m.	1½	3:15 p. m.	5:15 p. m.	Recovery
3	72	5-10-18	10:35 a. m.	1¾	2:30 p. m.	5-11— 8:00 a. m.	Death
16	70	5-14-18	10:15 a. m.	2	2:30 p. m.	5-15— 8:00 a. m.	Recovery
29	65	5-24-18	9:40 a. m.	2	11:05 a. m.	2:00 p. m.	Recovery
19	68	5-16-18	10:15 a. m.	2½	2:30 p. m.	5-18— 8:00 a. m.	Recovery
12	75	5-22-18	10:15 a. m.	2½	12:30 p. m.	5-26—11:00 a. m.	Death
22	83	5-15-18	10:00 a. m.	3	1:00 p. m.	5-18— 9:00 a. m.	Death
5	77	5-22-18	11:20 a. m.	3	12:30 p. m.	5-23— 1:00 a. m.	Death
18	94	5-18-18	10:35 a. m.	3½	1:00 p. m.	5-19— 8:00 a. m.	Recovery
18	94	5-24-18	10:25 a. m.	3½	10:00 a. m.	5-25— 2:00 p. m.	Recovery
20	73	5-17-18	10:15 a. m.	4	11:20 a. m.	5-18— 1:00 p. m.	Death
9	83	5-17-18	10:30 a. m.	4	11:20 a. m.	5-18— 8:00 a. m.	Death
21	96	5-22-18	10:40 a. m.	4	12:20 p. m.	1:25 p. m.	Death
24	67	5- 6-18	2:55 p. m.	½	11:00 p. m.	5- 7— 6:00 p. m.	*Recovery
29	65	6- 4-18	2:19 p. m.	½			†Negative
8	72	6- 4-18	2:20 p. m.	½			†Negative
25	93	5-27-18	10:30 a. m.	½	11:30 a. m.	5-28— 8:00 a. m.	†Recovery
29	88	5-15-19	9:40 a. m.	½			‡Negative
26	81	5- 5-19	9:50 a. m.	½	4:45 p. m.	7:00 p. m.	‡Recovery

*Flower heads fed. †Seed heads fed. ‡Bulbs fed.

⅛ and $^{4}/_{10}$ of a pound, one caused sickness and two were without result. Apparently the green seed-heads are about as poisonous as the leaves and stems. The number of tests, however, was not great enough to prove this conclusively. As a cause of poisoning in range sheep it is believed that the seed-heads of death camas are of very little importance.

Symptoms of Poisoning in Sheep by Foot-Hill Death Camas.

Small doses, from ¼ to ¾ of a pound, cause salivation or slobbering in nearly every case. A few cases show nausea and vomiting; there is often a marked increase in the rate of respiration sometimes amounting to panting. The breathing is very irregular; for a time it is rapid, then very slow. In some cases there is a muscular weakness, which is most noticeable in the hind-legs.

With larger doses, from one to two pounds, there is in addition to the above symptoms a period of dullness during which the animal stands with the back arched and the head and ears drooping. With still larger doses the animal becomes so weak as to be unable to rise.

In some cases the mucous membrane of mouth and tongue appeared blue; and two sheep showed such a spasmodic twitching of the muscles as occurs in strychnine poisoning.

Time Necessary for Symptoms of Poisoning to Appear.

The time which elapsed from the time of feeding until symptoms appeared varied from one to seven hours, the average being three hours and ten minutes. The time was slightly less for the larger doses. With doses of less than two pounds the time averaged three hours, twenty-two minutes; with doses of three pounds or more the average was two hours, twenty-five minutes.

Length of Time the Poisoned Sheep Were Sick.

The length of time through which the sheep remained sick was quite variable. After doses of ¼ pound to two pounds the animals were sick for from one to eighteen hours, averaging about five or six hours. As several of these sheep recovered during the night, we do not know exactly how long they were sick. Most of the sheep which died from the direct effects of death camas poisoning were sick from twenty to twenty-five hours; and one was down and unable to rise for nearly three days before it died.

Some Typical Cases of Death Camas Poisoning in Sheep.

Case 1. A yearling wether weighing 81 pounds was fed ¼ pound of the leaves of death camas at 11:10 a. m. May 5, 1918. At 2:55 p. m. it began to froth at the mouth and made attempts to vomit. The breathing was very irregular, alternately rapid and slow. At 4:30 p. m. the animal seemed to be getting better and by 5 p. m. it appeared to have recovered completely.

Case 2. About one month later, on June 4, 1918, the same sheep, now weighing 93 pounds, was fed ¼ pound at 2:35 p. m. At 3:50 p. m. it began slobbering; and at 4:05 p. m. it was nauseated and began to vomit. The breathing was at first fast and shallow, then slow and full, with occasional slight pauses. By 4:30 it had vomited an amount estimated at ¾ of a quart. Vomiting ceased soon afterward and by 4:50 the sheep was much better. When next observed, at 7:45 p. m., it was eating hay and appeared to have fully recovered.

Case 3. A yearling wether weighing 56 pounds was fed ½ pound of death camas leaves at 3:15 p. m. May 22, 1918. At 4:35 it was frothing at the mouth and trying to vomit. At 4:40 it was vomiting freely. At 7 p. m. it was still frothing at the mouth, but had ceased vomiting and was getting better. At 8 p. m. it seemed to have recovered. At 10 p. m. it was again slobbering a little. Next morning at 8 o'clock it had fully recovered.

Figure 8. Death Camas Poisoning.

Case 4. A yearling wether fed ¾ pound of the leaves at 9:25 a. m. May 24, 1918, began slobbering a little at 2:15 p. m. This gradually increased, and at 3:20 it was foaming freely at the mouth. At 4 p. m. it was still slobbering a little; but at 4:15 it began eating grass and seemed to have recovered fully. No other symptoms were noted.

Case 5. A ewe weighing 75 pounds was fed 1¼ pounds of death camas at 11:50 a. m. At 2:30 this sheep was grinding its teeth and slobbering freely. At 3:40 it was dull and stood with the head and ears drooping, still frothing freely at the mouth. At 4:30 the animal appeared to have nearly recovered, and was nibbling at feed.

Case 6. A ewe weighing 68 pounds was fed 1½ pounds of death camas at 10:40 a. m. May 9, 1918. It began to froth at the mouth at 1:20 p. m. At about 1:30 it vomited a considerable amount. At 2:30 it was slobbering freely, and stood with drooping head; showing a decided weakness in the hind legs. At 3:30 it was salivating less freely, but still stood with head drooping. At 4:30 it was getting better; but was still slobbering a little, and refused to eat. At 6:40 it appeared to have fully recovered.

Case 7. A ewe weighing 83 pounds was fed three pounds of death camas leaves on May 15, 1918, at 10 a. m. At 1:30 p. m. it was slobbering freely, was weak, and staggered when made to move. The breathing was labored, and at times the animal vomited. These symptoms continued, the animal growing worse until 3 p. m. and becoming weak enough by 4 p. m. to stagger when walking; it was then so weak

that it could easily be pushed over. The mucous membranes of the mouth and tongue were bluish. At 7:30 p. m. it seemed better, and did not appear so weak. At 9 a. m. next day it was down flat on the side and unable to rise. At 11 a. m. it had twitching movements of the muscles similar to those in strychnine poisoning. The animal remained down all that day. Next morning it was still down and appeared to be getting weaker; the breathing was labored and was accompanied by peculiar grunts. At 9 a. m. on the 18th it was found dead, but still warm.

Case 8. A ewe weighing 77 pounds was fed three pounds of death camas at 11:20 a. m. May 22, 1918. At 12:30 it was frothing at the mouth; by 1:30 it was frothing freely at the mouth and vomiting; these symptoms continued until about 2:30. By 2:50 the animal was weak in the hind legs and staggered when made to walk. The animal continued to get worse, and by 4 p. m. was very weak and dull, standing with head and ears drooping and the back arched. At 4:30 it vomited again. At 7 a. m. the animal was very dull, and staggered when made to move. It continued to grow worse until 10 p. m. Next morning, at 8 a. m. it was very weak and unable to get up. It remained in this condition all the forenoon; and died quietly at 1:30 p. m.

Meadow Death Camas (Zygadenus venenosus) Feeding Experiments with Sheep.

Only three feeding tests were made, as the plant is not at all abundant on the ranges in western Nevada; and material for the tests was necessarily limited. It is much less important on Nevada ranges than the foot-hill death camas. The results of the three feedings are summarized in Table II.

TABLE II

MEADOW DEATH CAMAS (*Z. venenosus*). THE GREEN LEAVES AND FLOWERS FED TO SHEEP.

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms appeared	Time of death or recovery	Final result
37	90	6- 9-19	9:45 a. m.	½			Negative
87	93	6-11-19	10:50 a. m.	1	1:40 p. m.	5:00 p. m.	Recovery
62	101	6-26-19	11:00 a. m.	2	11:50 a. m.	After 11:00 p. m.	Death

The experiments summarized in Table II show that this plant is poisonous and that amounts of one pound or more will cause serious poisoning in sheep. The symptoms produced by this plant are almost identical with those described for the foot-hill species, as will be seen from the following typical cases:

Typical Cases of Poisoning in Sheep, Meadow Death Camas.

Case 1. A ewe weighing 93 pounds was fed one pound at 10:50 a. m. At 1:40 p. m. it was foaming at the mouth. At 2:40 it was chewing cud, but still foaming at the mouth. At 5 p. m. it appeared to have recovered.

Case 2. On June 26, 1919, a ewe weighing 101 pounds was fed two pounds of the plant at 11 a. m. At 11:50 it was foaming at the mouth and vomiting. At 1 p. m. the respiration was rapid and irregular, varying from 55 to 70 per minute. It still frothed freely at the mouth, the froth being scattered all over the pen. By 4:15 it was very weak, staggered when walking, trying to vomit. The animal then appeared

TABLE III

DEATH CAMAS (*Z. paniculatus* and *Z. venenosus*). SUMMARY OF SYMPTOMS, FEEDING EXPERIMENTS WITH SHEEP.

Species of plant	Z. paniculatus																		Z. venenosus		
Part of plant fed	Leaves													Seed heads		Flower heads		Bulbs		Leaves and flowers		
Dose	1/8	1/4	1/3	1/2	1	1 1/2	1 1/2	1 2/3	2	2 1/2	3	3 1/2	4	1/8	1/4	1/16	1/8	1/8	1/4	1/8	1	2
Number fed	11	19	13	6	8	2	3	1	2	2	2	2	3	1	1	1	1	1	1	1	1	1
Number made sick		10	9	5	7	2	3	1	2	2	2	2	3			1	1		1		1	1
Number of deaths								*1		*1	2		3									1
Numbershowingslobbering		9	9	5	7	2	3	1	2	2	2	2	3			1	1		1		1	1
Retching and regurgitating		2	2	1			1	1	1	1	1	1	2			1						1
Respiration rapid, irregular		6		1	1			1			1		1			1						1
Weak and dull																						1
Weak in hind legs		1	1		1		1	1		1	1	1										
Hardly able to walk																						1
Reluctant to rise		2								1	2	2				1						1
Arching of back					2		1	1			1	1										
Head drooping					1		1				1	1				1						
Ears drooping					1		1	1			1	1				1						
Unable to rise										1	2		1									1
Mouth and tongue blue					1						1		1									1
Twitching of muscles											1		1									

*Death not directly due to zygadenus poisoning.

to be strangling, perhaps due to froth getting into the windpipe. It fell at 4:30 and could not get up again; at 4:45 it got up, but could barely walk. At 7 p. m. it was down and could not be induced to rise. It continued to get weaker and duller until 10:30 p. m., when the observer left for the night. The animal probably died soon afterward; as it was dead, cold and stiff, at 8 the following morning.

A Table of Symptoms of Death Camas Poisoning in Sheep.

Table III gives in very condensed and concrete form the effects of various quantities of death camas (*Z. paniculatus* and *Z. venenosus*) when fed to sheep (see page 18).

Feeding the Green Foot-Hill Death Camas to a Ewe with Suckling Lamb.

Reports from various sources made it seem possible that suckling lambs might be poisoned by alkaloids secreted in the mother's milk when the ewes fed upon this plant, and before the lambs were old enough to nibble at it. To test this matter, a ewe with a suckling lamb was fed the foot-hill death camas under the conditions listed in Table IV.

TABLE IV

FOOT-HILL DEATH CAMAS (*Z. paniculatus*). THE FRESH LEAVES FED TO A EWE WITH SUCKLING LAMB.

Animal No.	Date	Time fed	Amt. fed, lbs.	Weight lbs.	Time symptoms appeared	Time of recovery	Effect on ewe	Effect on lamb
37	4- 1-19	1:30 p. m.	½	98			Negative	Negative
	4- 2-19	3:30 p. m.	½				Negative	Negative
	4- 3-19	1:30 p. m.	½				Negative	Negative
	4- 4-19	1:30 p. m.	½				Negative	Negative
	4- 9-19	9:00 a. m.	½				Negative	Negative
	4-10-19	8:40 a. m.	½				Negative	Negative
	4-11-19	9:00 a. m.	½				Negative	Negative
	4-16-19	8:40 a. m.	½				Negative	Negative
	4-17-19	8:30 a. m.	½		11:30 a. m.	4:00 p. m.	Recovery	Negative
	4-18-19	9:30 a. m.	1		10:00 a. m.	11:00 a. m.	Recovery	Negative
	4-19-19	9:00 a. m.	½		7:30 p. m.	4-20—8:00 a. m.	Recovery	Negative
	4-22-19	10:00 a. m.	1½		1:00 p. m.	2:00 p. m.	Recovery	Negative

The tests recorded in Table IV show that although the ewe was fed amounts varying from ½ pound to 1½ pounds and was made sick four times, still the suckling lamb was not affected during any of the twelve feedings of its mother.

In the case of the ewe these feedings would also seem to indicate that there is little or no tendency for a sheep to become immune to the poisonous effects of death camas after feeding repeatedly upon it.

Feeding Green Foot-Hill Death Camas to Cattle.

Table V summarizes the results of eighteen tests in which the fresh green plants were fed to cattle (see next page).

It appears from this table that cattle are quite susceptible to the poisonous principle of the foot-hill death camas. Out of the eighteen feedings, ten made the animal sick; but no deaths occurred. It was almost impossible to get cattle to eat more than two pounds of the plant; because they soon became so violently sick that they vomited up all the material eaten. Two small feedings of ¼ pound each had no apparent effect upon the animals fed; but quantities of from ⅜ of a pound to two pounds usually caused symptoms of poisoning. In some instances poisoning was quite severe, reducing for several days the vigor and strength of the animal.

TABLE V

FOOT-HILL DEATH CAMAS (*Z. paniculatus*). THE GREEN LEAVES FED TO CATTLE.

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms appeared	Time of death or recovery	Final result
1	137	4- 8-19	8:00 a. m.	¼			Negative
6	203	4-12-19	8:45 a. m.	¼			Negative
1	137	4-10-19	8:30 a. m.	¼			Negative
4	165	4-10-19	9:00 a. m.	½	11:30 a. m.	3:00 p. m.	Recovery
4	165	4-15-19	9:00 a. m.	½	11:00 a. m.	3:30 p. m.	Recovery
4	165	4- 8-19	8:30 a. m.	½	9:30 a. m.	4:30 p. m.	Recovery
6	203	4-10-19	9:45 a. m.	½			Negative
1	137	4-12-19	8:30 a. m.	½			Negative
1	143	4-16-19	9:00 a. m.	½			Negative
4	150	4-25-19	10:50 a. m.	¾	About 12:00 m.	4-26—8:00 a. m.	Recovery
5	208	4-10-19	10:20 a. m.	¾			Negative
5	208	4-16-19	10:20 a. m.	¾	10:50 a. m.	4:00 p. m.	Recovery
5	208	4- 8-19	9:00 a. m.	1	10:00 a. m.	4:30 p. m.	Recovery
5	208	4-12-19	10:00 a. m.	1	11:30 a. m.	4-13—4:00 p. m.	Recovery
6	193	4-16-19	11:30 a. m.	1	1:00 p. m.	4:00 p. m.	Recovery
8	220	4-14-19	10:20 a. m.	1¼			Negative
5	208	4-19-19	10:00 a. m.	1¼	10:20 a. m.	4-22—8:00 a. m.	Recovery
6	193	4-25-19	9:30 a. m.	2	10:00 a. m.	4-28—8:00 a. m.	Recovery

Symptoms Exhibited by Poisoned Cattle.

Slobbering was not so common a symptom in cattle as in sheep, while vomiting was much more common and more profuse. This vomiting made the animals appear very thin until they recovered sufficiently to eat. A rise in the rate of respiration was a common symptom. Severely poisoned cattle became very weak and dull; the gait was unsteady, particularly in the hind-legs, the animals sometimes stumbling with the hind feet. A few were either so weak that they were unable to get up, or else they would fall over when walking. Grinding of the teeth and diarrhea were each observed in a single animal.

Length of Time Required for Symptoms to Appear in Cattle.

The time from the middle of the feeding period until cattle became sick varied from 20 minutes to 2½ hours, averaging about 1 hour and 7 minutes. They remained sick for from 3 to 22 hours, averaging 11½ hours.

Some Typical Cases of Death Camas Poisoning in Cattle.

Case 1. A calf weighing 165 pounds was fed ⅜ of a pound of death camas leaves at 9 a. m., April 10, 1919. At 11:30 it was sick and vomited freely. It remained sick, vomiting frequently, until 1:30. At 3 p. m. it appeared to have recovered.

Case 2. A calf weighing 150 pounds was fed ½ pound of the leaves at 10:50 a. m., April 23, 1919. It vomited between noon and 1 p. m. At 3 p. m. it was lying down and appeared dull. When made to get up it walked with an unsteady gait. At 5 p. m. it was up and eating hay. At 8 a. m. next day it was still slobbering; but by 5 p. m. it had apparently recovered.

Case 3. A calf weighing 208 pounds was fed one pound of death camas at 9 a. m., April 8, 1919. At 10 a. m. it began vomiting and frothing slightly at the mouth. At 11:20 it was breathing at the rate of 94 times per minute. At 2:45 it had stopped vomiting and the respiration had fallen to 34 per minute. The animal was still slightly sick at 3:30 p. m. but was eating, and appeared to have nearly

recovered at 4:30 p. m. At 8:30 next morning it was walking with a peculiar gait, frequently stumbling with the hind feet.

Case 4. A calf weighing 208 pounds was fed 1½ pounds at 10 a. m., April 19, 1919. At 10:20 a. m. it began vomiting, and vomited again at 11:20 a. m. Was grinding the teeth almost constantly from 10:30 until noon. At noon the respiration was 40 per minute. This calf was able to get up at 2 p. m., but walked with a very unsteady gait, especially noticeable in the hind legs. This condition continued until 9:30 p. m. At 8 o'clock next morning it was still weak and looked very thin.

Figure 9. Death Camas Poisoning. This calf shows slobbering after eating death camas. This symptom is more common in sheep than in cattle.

Figure 10. Death Camas Poisoning. This calf shows a common symptom—weakness in the hind-legs.

It ate a little hay, but soon quit; the bowels were quite loose. At 8 a. m. on April 22, it appeared to have recovered; but was still thin and a little dull.

Case 5. A calf weighing 193 pounds was fed two pounds of death camas leaves at 9:30 a. m. At 10 a. m. it began to slobber, the respiration then being 56 per minute. It vomited between noon and 1 p. m. At 3 p. m. it was still dull, and walked with an unsteady gait when made to get up. Next morning it appeared to have fully recovered.

Meadow Death Camas, Feeding Tests with Cattle.

Owing to the scarcity of material, few tests were made with this species. The five feedings made are summarized in Table VI.

TABLE VI

MEADOW DEATH CAMAS (*Z. venenosus*). THE GREEN LEAVES FED TO CATTLE.

Animal No.	Weight lbs.	Date fed	Time fed	Amount fed, lbs.	Time symptoms appeared	Time of death or recovery	Final result
8	220	6-11-19	2:00 p. m.	½			Negative
9	235	6-11-19	2:30 p. m.	½			Negative
1	138	6-11-19	11:45 a. m.	½	12:45 p. m.	2:40 p. m.	Recovery
10	330	6-11-19	2:40 p. m.	1			Negative
8	220	6-12-19	8:45 a. m.	1½	1:00 p. m.	6-13—8:00 a. m.	Recovery

Summary of Results of Feeding Death Camas to Cattle.

Table VII shows graphically the effect of various amounts of death camas when fed to cattle in experimental tests.

TABLE VII

DEATH CAMAS (*Z. paniculatus* and *Z. venenosus*). SUMMARY OF SYMPTOMS, FEEDING EXPERIMENTS WITH CATTLE.

Species fed	Zygadenus paniculatus								Zygadenus venenosus				
Dose	½	¾	1	1½	2	3	4	5	¾	1	1½	2	2½
Number fed	2	3	5	2	3	1	1	1	1	1	1	1	1
Number made sick		2	2	1	3		1	1			1		1
Number showing:													
Slobbering		1	1		1			1					
Regurgitating		2	2		2		1	1			1		1
Dull			2				1	1					
Unsteady gait			2		2		1	1					1
Reluctant to rise			2										
Respiration rapid				1	1								
Stumbling on hind legs					1								
Unsteady on hind legs					2		1						
Fall, and hardly able to get up					1								
Grinding teeth							1						1
Weak					1		1	1					1

Conditions Under Which Death Camas Poisoning Is Most Likely to Occur.

As has been stated, death camas contains a bitter substance extremely distasteful to both sheep and cattle. Consequently the plant is eaten by these animals only under stress of extreme hunger or prolonged starvation.

Most of the cases of death camas poisoning have occurred early in the spring. This is a time of year when all palatable vegetation is scarce, and range animals are often poor and hungry, depending of course upon the way in which they have been handled during the winter. Under these conditions, on a range supporting very little palatable vegetation, hungry animals will eat almost any plant in order to satisfy their hunger. This is well illustrated by a loss of cattle which took place in Elko County.

A herd of cattle were being trailed through sagebrush country where the grass and weeds were just beginning to grow, but where a considerable number of death camas plants had already made their appearance. The cattle were thin and hungry, and at every opportunity they bit off the death camas plants. A rather large number of cattle died as a result of this drive. Some of the poisoned animals that were left behind recovered; those that were driven hard in most cases died on the trail.

In regard to cattle, then, it may be said that the following are the range conditions under which death camas poisoning is most likely to occur: (1) When hungry stock are unloaded from the cars in spring and turned out on a depleted range where death camas is common, and there is very little grass; (2) When cattle are trailed from one range to another in the spring when all palatable feed is scarce; (3) When hungry animals in poor condition are turned out to rustle for themselves in the early spring before the grass is up, so that they are forced to graze any and all plants in order to satisfy their hunger.

When sheep are grazing openly and quietly on a range, they show great care in the selection of the forage they eat. However, when they are being trailed from one place to another, they have no chance to

choose what they will eat, with the result that they eat anything that is not absolutely repellant. If death camas is common, and it usually is, they eat so much of it that they get more of the poison than they can throw off. They are constantly forced to move along on the trail by dogs and herders, and death naturally follows.

Figure 11. Thin and Hungry Cattle on Poor Pasture. Early in the spring animals in this condition are ravenous for green feed. They will then eat death camas or other poisonous plants which ordinarily they would not touch.

Figure 12. Cattle on Good Mountain Pasture. Well-fed animals on good range will ordinarily avoid poisonous plants almost wholly.

It should always be remembered that when a sheep is hungry it usually eats greedily the plant on which it is feeding, or else rushes to another plant for fear some other sheep will get there before it does. But when sheep are grazing openly and quietly, they nip off only the tender and juicy parts of the plant, the leaves and young stems, and carefully select the plants on which they feed.

How to Avoid Death Camas Poisoning in Sheep and Cattle.

Evidently in order to avoid losses on a range where death camas is common, sheep should be so handled that they are never bunched up nor extremely hungry. If they are to be driven from one range to another, it is best to allow them to graze for an hour or two in the morning just as openly and quietly as possible before starting to move them. This will allow all the animals to fill with good forage and they will then use greater care in the selection of their food for the remainder of the day. This would not be the case if they were started on the trail immediately after leaving the bed-ground.

Figure 13. Sheep Grazing at Will on Sagebrush Range. When allowed to feed quietly in scattered formation, sheep will ordinarily wholly avoid death camas and many other poisonous plants.

Another very important point is to get the sheep off the bed-ground just as early in the morning as possible. When a sheep beds down at night it is usually full and contented. By morning it is beginning to get rather empty, and the longer it is kept on the bed-ground the hungrier it becomes; it is then far more apt to be poisoned when it gets out on the range where the death camas is common.

In most of the cases of death camas poisoning thus far observed, the animals were poisoned during the forenoon. This is due to the fact the attractiveness of the plant decreases as the stomach becomes full. Thus plants which may seem to be highly palatable and to be relished during the morning hours are often not touched at all later in the day. This is quite true of the death camas. It is grazed chiefly during the early morning hours, and is seldom touched by an animal whose stomach is nearly full. Therefore it is highly important that the sheep should be so handled during the early morning hours that they will have the greatest freedom in the selection of their range forage; if possible, during this part of the morning they should be grazed on range free from death camas, or where it has only a very scattering growth.

In Nevada the prevailing method of handling sheep, especially in the spring of the year, is to establish a main camp from which the sheep are grazed daily until all the feed in the immediate vicinity of the camp has been eaten out to a distance of two or three miles in every direction. This requires long daily drives back and forth in order to get away from range that has already been grazed. Thus the sheep trail over the same ground each day, until all the forage on the range around the bed-ground has been completely eaten off.

This method of handling can only result in all the plants being eaten, whether poisonous or not; for the most attractive ones are first grazed, and when these are gone the less palatable ones are left to be eaten, including, of course, the death camas.

In order to avoid the losses which result from such improper methods of handling sheep, they should be allowed to bed down wherever they happen to be when night comes. They will then always be on fresh feed in the morning. The variety of forage from which to choose will be much greater; and the probability of poisoning will be far less; providing, of course, that the animals are gotten off the bed-ground early in the morning and are allowed to spread out and graze openly and quietly, each ewe with her lamb. Close-bunched grazing, running, trailing, and massing should be avoided; not only to reduce losses from poisonous plants, but also for the good of the ewe and her lamb, and for the most full and effective use of the range forage.

Remedies for Death Camas Poisoning.

For animals poisoned by death camas there is known at present no practical remedy. The best treatment is to let the poisoned animals entirely alone, disturbing them only when it is absolutely necessary. After an animal has been poisoned it is very much weakened and should be given all the care that is practicable on the range. If it can be kept on good feed and driven just as little as possible for the first two or three days, it will often recover rapidly.

SECTION II

The material included in this section is of greater interest to chemists and veterinarians than to livestock owners.

POST-MORTEM CONDITIONS

Autopsies upon six sheep whose death was caused by death camas in feeding experiments showed the following post-mortem conditions:

There appeared to be no outstanding lesions which would serve to indicate a characteristic effect due to poisoning by this plant. On the whole, the lesions shown were those of a general toxemia. The conditions were such as are found more or less uniformly, with individual variations, after death caused by the ingestion of various toxic or semi-toxic plants.

Various degrees of congestion in the gastro-intestinal tract and in its lymphatic system appeared to be prominent symptoms. In some instances the same condition was also found in the kidney, spleen, and liver. The lungs appeared to show no change. In some cases the heart displayed small hemorrhages beneath the epicardium and endocardium, characteristic of toxemia. Considerable quantities of free fluid were observed in the thoracic and abdominal cavities.

THE ACTIVE PRINCIPLE OF DEATH CAMAS

It has long been known that alkaloids are partially, if not wholly, responsible for the poisonous properties of the death camas. Different investigators have studied various species of *Zygadenus,* and the lack of uniformity in the results obtained is not surprising. In the bulk of the work reported it is stated that alkaloids have either been isolated or detected; a single worker found resins in the plant which had poisonous properties. Later attempts to verify these findings in closely related species resulted in failure.

Two physiologically active resins were found by Vejux-Tyrode in 1904 in the bulbs of *Zygadenus venenosus* from Montana. From one of the resins he isolated a basic body which he designated zygadinein and an acid—zygadenic acid. In animal experiments he found the zygadinein to be the active principle. When given in minute doses to guinea pigs, rabbits, and dogs it produced salivation, staggering and respiratory paralysis followed by death, in some cases in a few minutes but usually within a few hours. In 1913 the chemists of the Wyoming Station, F. W. Heyl and F. E. Hepner, investigated *Zygadenus intermedius* for similar toxic resins, but were unable to isolate any toxic substance from the resin or even to establish the toxicity of the resin itself.

The work of early investigators consisted of color tests made upon impure products and led to conclusions that the alkaloids in the species tested belonged to the veratrine group.

In 1903 George Heyl obtained an alkaloid from a California species of *Zygadenus.* The alkaloid found amounted to 0.4%. It was soluble in ether and nearly insoluble in water. Its melting point was 134–135°. It formed a crystalline hydrochlorid.

Alkalodial analyses of *Zygadenus intermedius* were made in Wyoming in an endeavor to determine the quantity of alkaloidal material present in the different parts of the plant. On account of the lack of suitable methods for the determination, the results are probably not so

accurate as might be desired and show only a fair degree of uniformity. Figures for the amounts found in the dried leaf varied from 0.57% to 0.66%; bulb, 0.188% to 0.57%; flower, 1.07% to 1.35%; root, 0.306% to 0.32%.

A quantity of material was prepared and submitted to Dr. Phillip Mitchell and Mr. Geo. Smith for toxicological experiments. The material used in these experiments was not the more highly purified crystallized alkaloid which was reported on later. It was found that when injected intraperitoneally a quantity between 4.6 mg. and 5.1 mg. would produce death in a guinea pig. When administered by mouth a comparatively large quantity was required for fatal effects in the guinea pig. The larger amount necessary was partially accounted for by the fact that the material caused vomiting. In the guinea pig the effects of the material appeared to be the same after subcutaneous or intraperitoneal injection or after feeding.

The mixed alkaloids cause vaso-dilatation and apparently affect the cardio-inhibitory center, slowing the heart action. Respiration was slowed. After doses approaching the fatal quantity the heart-beat becomes rapid and irregular and there is convulsive respiration. In dogs the fatal dose given intravenously stopped the heart before respiration ceased. When either injected or fed, it had a powerful action both as a purgative and an emetic.

Later, in the Wyoming experiments, a more highly purified alkaloid was obtained which could be crystallized from alcohol and benzene. The crystalline material from benzene melted at 200–210° and was found to have the formula $C_{39}H_{63}NO_{10}$. The physiological action was tested by Dr. Phillip Mitchell, who reported its effects to be different from those found for the mixed alkaloids. Its behavior was in general much like the alkaloid veratrine and it required comparatively large quantities to kill guinea pigs. Unlike the mixed alkaloids it had no noteworthy effect on the heart and apparently caused complete loss of muscular control.

In 1918 Dr. C. A. Jacobson of the Nevada Station reported obtaining a new alkaloidal product from *Zygadenus paniculatus*. This alkaloidal product was designated by him as "Z-alkaloid." The crude alkaloid was prepared by extracting the ground and dried plant with 95% alcohol, concentrating the extract to a sirup and pouring into a dilute solution of tartaric acid to remove resins and other impurities. The clear acid solution was further purified by extraction with ether; and the crude alkaloid was precipitated by the addition of sodium carbonate. The precipitate was an amorphous sticky mass poisonous to rabbits. The liquid containing the precipitated solid matter was extracted with ether. It was found that if the ether was completely removed on the water bath, the material would then undergo violent effervescence and the resulting product would no longer be poisonous. If, however, the last of the ether was allowed to evaporate in the air at ordinary temperatures no effervescence took place and the resulting material retained its potency. Further purification was effected by re-solution in tartaric acid, removal of impurities with ether, neutralization and extraction with ether and chloroform.

The more purified Z-alkaloid had an increased toxicity, about 0.35 gram being found to be lethal for rabbits when administered by mouth.

The Z-alkaloid, which constituted about 0.3% of the dried plant, was soluble in ethyl and methyl alcohol, chloroform, acetone, and less so in benzene and carbon tetrachlorid. On standing several months, it resinified to a white substance without change in its toxicity or solubility. On long standing, an alcohol-insoluble crystalline material separated to the extent of about 1% of the original mass, but on account of the small quantity obtained its physiological action could not be determined. Various compounds of the Z-alkaloid were prepared; and from the data obtained it appeared that it is not the same as the compound named Zygadinein which was obtained at the Wyoming station.

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EFFECTS OF DIFFERENT SYSTEMS AND INTENSITIES OF GRAZING UPON THE NATIVE VEGETATION AT THE NORTHERN GREAT PLAINS FIELD STATION

By

J. T. SARVIS, Assistant Agronomist, Office of Dry-Land Agriculture Investigations
Bureau of Plant Industry

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INTRODUCTION.

During the period when the beef-cattle industry on the free ranges of the Great Plains area was in a thriving condition, meager authentic information was recorded regarding the best utilization of the native vegetation. This information is lacking because there was little demand at that time for the investigation of the subject through a systematic study of grazing problems. The range was looked upon as an inexhaustible supply of forage for all classes of stock. If the range became short in one place, it was only necessary to move to a new area. With the advent of the dry-land farmer and the consequent splitting up of the range, however, grazing became more intensified, and a demand arose for information regarding range and pasture management. The problem was not only how to restore overgrazed areas, but also how to graze an area that was still in a high state of production in order to afford the best utilization of the forage and to maintain the range in good condition. This problem

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tinuous system of grazing, they did not cover the most important phase of the grazing problem from the standpoint of the native vegetation. A continuous system of grazing does not take into consideration the full requirements of plant growth, nor does it afford the maximum utilization of the vegetation without the serious effects, both to the cattle and the vegetation, attendant upon close grazing.

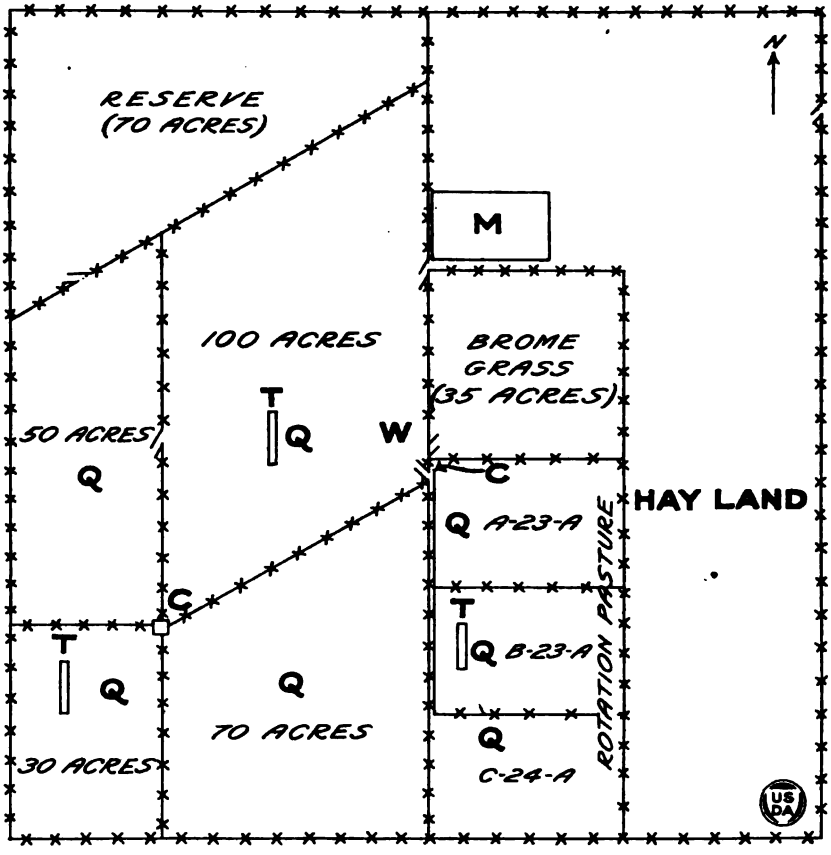

FIG. 1.—Field plan of the pastures used in the cooperative grazing experiment: T, Isolation transect; Q, mapped quadrats; C, corrals and water trough; W, deep well; M, mowing experiment.

The United States Department of Agriculture has for a number of years been conducting investigations in connection with grazing problems. The benefits to the vegetation of "rest periods" and the "alternation of pastures" have been advocated for some years,[1] and as early as 1895 rotation grazing was discussed as follows:

Clearly, then, if the grazing quality of the ranges is to be improved, they must be so treated that the nutritious native species of grasses and forage

[1] Smith, Jared G. Grazing problems in the Southwest and how to meet them. U. S. Dept. Agr., Div. Agros., Bul. 16, 47 p., 9 figs. 1899.
Cotton, J. S. Range management. *In* Yearbook, U. S. Dept. Agr., 1906, pp. 225–238, pl. 12. 1907.

plants can spread by means of the ripened seed. This can be accomplished by dividing the range up into separate pastures and grazing the different fields in rotation.[2]

The Forest Service of the United States Department of Agriculture later developed and put into practice in the management of grazing lands within the national forests the system of "deferred and rotation grazing."[3] A similar system has also been applied on a large range in the Southwest.[4]

In 1918 a 70-acre pasture managed under the system of deferred and rotation grazing was established. This is locally referred to as the "rotation pasture." It is not a new system of range management developed with the experiment at Mandan, but rather a direct application in the northern Great Plains of a system of grazing already highly developed. This system, as applied in this experiment, follows closely the detailed plan outlined in the Yearbook for 1915.[5] The only change made at Mandan, in the plan, is to transfer the cattle from the division grazed in the fall to the one grazed in the spring of the same year. This is done for a short time near the close of the season when the feed supply in the fall division becomes short and inferior to that in the spring division. There is usually some growth made in the spring division after the cattle are transferred to another unit. If this growth is grazed after maturity there are no ill effects to the vegetation, and there is no reason why this secondary growth should not be utilized if necessary. Another change is that the number of cattle is not reduced during the second season of fall grazing on a unit.

In 1921 a field of brome-grass was established adjoining the pastures. This will be grazed in direct relation to the native pastures under the continuous system of grazing and should furnish information on the relative value of a cultivated grass as compared with the native vegetation for grazing purposes. It was planned to start this pasture in 1919, but the seasons were so unfavorable that it was not possible to do so until the spring of 1921. The addition of the cultivated pasture now makes the grazing experiment very complete without being too complicated. While it would have been desirable to start all pastures at the same time, the fact that they were not so started should not make the results obtained any less valuable. Each pasture or system of grazing must stand on its own merit. In order to be of most value, a pasture under any system of grazing must maintain its productiveness over a series of years and not be greatly influenced by conditions that may obtain for one or two seasons only.

LAND USED FOR THE EXPERIMENT.

The area of land used for the grazing experiment was formerly a school section, located about 3½ miles south of Mandan, upon what is locally known as the Custer Flats. The section for a number of

[2] Smith, Jared G. Forage conditions of the prairie region. *In* Yearbook, U. S. Dept. Agr., 1895, pp. 309–324, figs. 70–74. 1896.
[3] Sampson, Arthur W. Range improvement by deferred and rotation grazing. U. S. Dept. Agr. Bul. 34, 16 pp., 5 pls. 1913.
[4] Jardine, James T., and Hurtt, L. C. Increased cattle production on southwestern ranges. U. S. Dept. Agr. Bul. 588, 32 pp., 12 pls., 2 figs. 1917.
[5] Jardine, James T. Improvement and management of native pastures in the West. *In* Yearbook, U. S. Dept. Agr., 1915, pp. 299–310, pls. 69–72. 1916.

years previous to 1915 had been used as hay land. Legislative action, both State and National, made it possible for the United States Department of Agriculture to obtain this section in lieu of two other sections of public land in North Dakota. This land when obtained in 1915 was considered worth about $35 per acre.

The section is level prairie with the exception of about 100 acres in the northwest corner, which is rolling and cut by ravines. This rough land is practically all in the reserve pasture and is not included in the area used in the experiment, the soil of which does not differ naturally from other vast areas in the western part of North Dakota. The first objection that might be raised regarding this section is that it is too good for grazing. This may be true, but it is not too good for a grazing experiment. No one connected with this experiment would advise using similar land for grazing purposes, especially when rough land is available. The land is so uniform that the pastures are as comparable as it could be hoped to obtain them. Uniformity of the land and uniformity of the vegetation are the conditions that are absolutely necessary in order properly to conduct an experiment of this kind and secure reliable results. It is necessary to eliminate all unknown factors as far as possible. The factors of uniformity of land and vegetation need cause no special difficulty in connection with a consideration of the results obtained in this experiment.

Another question that arises in regard to the experiment is, will the results obtained be applicable to other parts of the Great Plains? It should be recognized that the present experiment is designed to determine the effects of different systems and intensities of grazing upon the native vegetation and the cattle dependent upon it. The results of this experiment should apply to any area of land in the northern Great Plains having a similar plant cover that produces enough vegetation to be of grazing value. The unit area of land required for the best system of grazing will vary in different localities and can not be determined in any one area for all sections. The value of the results of this experiment is dependent upon the determination of the best system of grazing to follow in order to maintain the range at a high degree of productiveness. Any system that will accomplish this will also improve a range that has already been depleted by overgrazing. It is believed that the results recorded in these pages will apply to most of western North Dakota and South Dakota and to parts of Wyoming and Montana.

This land in 1915 would have been considered in excellent condition for grazing, not because of the very favorable season, but because of the normal density of the vegetation. The area had not, at least within recent years, been depleted by overgrazing. The experiment was, therefore, started on land that was in a high state of production of native forage. The problem was not to bring back into a state of productiveness an area that had been depleted by overgrazing, but rather to determine the best method of utilizing a satisfactory stand of forage. In order to study the other side of the problem it was first necessary to overgraze a pasture. This was designed to be done in the 30-acre pasture. This pasture is still being heavily grazed, and it will be some time before it is ready for the

restoration process. The depletion or destruction of the native vegetation by overgrazing with cattle does not occur suddenly;[6] it is cumulative, and an overgrazed pasture may continue to produce a limited quantity of feed for a number of years.

RELATION OF PRECIPITATION TO NATIVE FORAGE PRODUCTION.

The amount of precipitation during April and May exerts a greater influence upon the annual production of native forage than upon the production of small-grain crops during the same season. A normal rainfall during the early season practically insures a reasonable growth of native forage, even though the later rainfall is below normal. Such a condition may mean a very light crop or the failure of the small grains. This point was well illustrated during 1921. The rainfall during April and May was above normal, while during June and until the last week in July it was much below normal. As a result the native forage produced more than in 1920, while the small grains were decidedly reduced in yield.

The mean annual precipitation for the 45-year period from 1875 to 1919, inclusive, was 17.17 inches.[7] The mean seasonal precipitation from April 1 to August 31, inclusive, was 11.84 inches during the same period. The month of maximum precipitation is June, with a mean of 3.51 inches for the 45-year period.

TABLE 1.—*Annual precipitation near Mandan, N. Dak., by months, for the 6-year period from 1916 to 1921, inclusive.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal, Apr.-Aug.	Annual.
1916	0.28	0.09	1.88	0.93	1.69	2.25	3.55	2.04	0.92	0.27	0.07	1.10	10.46	15.07
1917	.28	.19	.35	1.87	.35	2.56	1.58	.89	1.97	.05	.03	.19	7.25	[1] 10.31
1918	.20	.11	.45	2.61	2.45	.68	2.47	2.03	.63	.27	.45	1.02	10.24	13.37
1919	.08	.80	.83	1.72	3.95	1.12	.85	1.22	.49	.98	1.19	.25	8.86	13.48
1920	.52	.20	1.21	.58	1.72	1.85	2.68	1.81	1.29	.25	.37	.21	8.64	12.69
1921	.18	.09	.79	2.59	3.05	.82	3.38	.25	1.58	1.39	.87	.24	10.09	15.23
Mean	.26	.25	.92	1.72	2.20	1.55	2.42	1.37	1.15	.54	.50	.50	9.26	13.36

[1] Lowest during 47 years.

While the grazing experiment has been in progress it has passed through the driest series of years that have obtained in this section during the period of record. The driest consecutive six years previous to 1916 was from 1885 to 1890, inclusive, with an annual mean precipitation of 14.33 inches. The mean seasonal precipitation from April 1 to August 31, inclusive, for the same period was 10.05 inches. Table 1 shows the annual precipitation by months for the six-year period from 1916 to 1921, inclusive, i. e., during the period covered by the grazing experiment. The annual precipitation of these six years ranged from 10.31 to 15.23 inches and averaged 13.36 inches. The seasonal precipitation from April 1 to August 31, inclusive, for the same period averaged 9.26 inches.

[6] Wilcox, E. V. The grazing industry. Hawaii Agr. Exp. Sta., 91 pp. 1911. Bibliographical footnotes.

[7] Data based upon the records of the United States Weather Bureau at Bismarck, N. Dak., and those recorded since 1914 at the Northern Great Plains Field Station, Mandan, N. Dak.

DEFERRED AND ROTATION SYSTEM OF GRAZING.

This system of grazing is designed to allow each division of the pasture to mature a crop for two successive years before it is harvested by the cattle in the fall of each year. Grazing on each division is deferred and rotated, so that each unit has an equal chance to produce a maximum crop normally before it is disturbed.

The seeds of the grasses which are scattered on the ground are aided in their planting by the trampling of the cattle. This manner of reseeding is highly important in some sections.[8] However, in this region the advantage gained by reseeding for most of the species of plants is not as great as it would be in an area that has been overgrazed for a number of years. As far as it has been possible to determine, there has been no measurable increase in any of the species by reseeding in the rotation pasture. This has no doubt been influenced to some extent by the very unfavorable seasons. The greatest advantage gained here by this system of grazing is in the physiological effect upon the plants. The fact that the plants are allowed to mature a crop normally permits them to store up food in their root systems to aid in the production of the next year's crop. It is a well-recognized botanical fact that the surest way to kill plants is to keep them from producing green shoots. The continual removal of the early green shoots by grazing gradually reduces the vitality of the plants until they finally die. Some species are much more readily killed in this manner than are others. This fact is well illustrated in the case of *Stipa comata* (western needle grass). In the 30-acre pasture this grass has been greatly weakened and thinned out, while in the frequently clipped quadrats it has been entirely eliminated.

Figure 2 shows the plan of the deferred and rotation grazing system. Section 1 illustrates the system presented in the Yearbook of the Department of Agriculture for 1915, page 309. Section 2 illustrates a similar plan but one in which the two successive fall grazing periods proceed from C to A to B, while in section 1 they proceed from C to B to A. It will be noted that section 2 produces the more uniform pattern and is ready to repeat directly in 1924, while in section 1 it repeats indirectly in 1924. In section 1, division B has four rest periods in 1919 and 1920, which do not occur in any other division during the cycle. Section 1 has been followed in this experiment.

The seasonal grazing of the 70-acre rotation pasture illustrates the application and management of deferred and rotation grazing. These 70 acres are divided by cross fences into three parts, approximately equal in size. The divisions are designated A, B, and C. When this pasture was first grazed in 1918, division A was grazed first, or in the spring; division B second, or in the summer; and division C was allowed to mature its crop normally and was grazed third, or in the fall. In 1919 division B was grazed first, A second, and division C was again deferred until the third period, or after the crop had matured without disturbance. During the following seasons divisions A and B are in turn treated as was division C

[8] Sampson, Arthur W. Natural revegetation of range lands based upon growth requirements and life history of the vegetation. *In* Jour. Agr. Research, v. 3, pp. 93–148, 6 figs., pls. 12–23. 1914.

during 1918 and 1919. The grazing starts each season, so that a division which for two years has been deferred until the fall before grazing is not grazed first but second. This is done to allow any seedlings that might start from the second year's seeding a chance to become more firmly established before the division is grazed. This is the reason that the cycle as outlined in Figure 2, section 1, is not ready to repeat directly in 1924.

The details of the system of deferred and rotation grazing are more fully discussed in other publications of the United States Department of Agriculture.[9]

The grazing periods at Mandan have been as follows: Spring, from May 15 or June 1 to July 1 or July 15; summer, July 1 or July 15 to September 1 or September 15; fall, from September 1 or September 15 to October 15 or November 1. These periods of grazing fit the requirements of the vegetation in a very satisfactory manner. In the spring the vegetation has made a good growth by May 15 or June 1 and makes rapid growth during the grazing period, so that the cattle obtain plenty of feed. In the summer period there is still some growth taking place, and a few species have matured. By the time the fall period is reached all the valuable species in the division unpastured to this time have matured their seeds and are ready for harvest. The three Artemisias, however, have not matured their seeds by this time, but these plants are weeds, and their propagation is undesirable. During the years the rotation pasture has

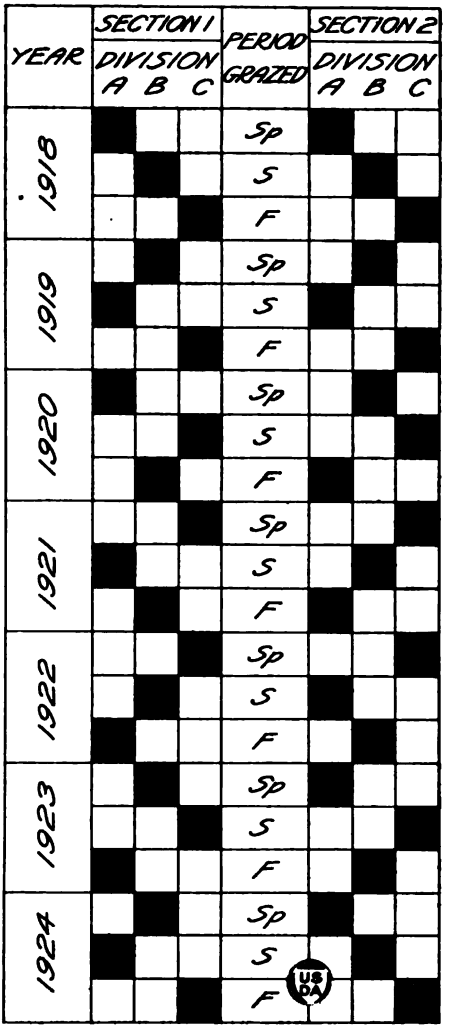

FIG. 2.—Diagram showing the order of grazing the three divisions of the deferred and rotation pasture for a complete cycle and the first season of the next. Columns *A*, *B*, and *C* represent the three divisions of the pasture. Each year is separated into three periods indicative of spring (Sp), summer (S), and fall (F) grazing periods. Grazing periods are shaded, rest periods unshaded. The first part of the diagram designated as section 1 illustrates the plan being followed; section 2 represents a more uniform plan that has been worked out. These sections differ in the order of the rotation. In section 1 the order of fall grazing is *C*, *B*, *A* and in section 2 *C*, *A*, *B*.

[9] Jardine, James T. Improvement and management of native pastures in the West. *In* Yearbook, U. S. Dept. Agr., 1915, pp. 299–310, pls. 69–72. 1916.
——— and Anderson, Mark. Range management on the national forests. U. S. Dept. Agr. Bul. 790, 98 pp., 4 figs., 32 pls. 1919.

been in operation there have been little heading and seeding of blue grama grass (*Bouteloua gracilis*) in the fall division. There have been heading and seeding of this grass in the spring-grazed division, however. Grazing or mowing seems to stimulate its production of flower stalks and heads. The vitality of the seeds is very low, and only a few ever germinate. This fact is further evidence that the value of this grazing system lies largely in the effects of normal development upon the plants.

PERIOD OF GRAZING AND CATTLE USED.

The period of grazing has been five months during the warm season. Grazing has started in the spring from May 15 to June 1 and continued to October 15 or November 1. Three years out of the

FIG. 3.—Two-year-old steers used in the grazing experiment. These steers are of the type used at the Northern Great Plains Field Station, near Mandan, N. Dak., during 1921.

six the seasonal grazing has started in May, and three years on June 1. This experiment does not take into consideration winter grazing, which should not be depended upon in this section of the Plains. The severe conditions of the winter of 1921–22 emphasize this fact.

The cattle used for the grazing work have been 2-year-old grade steers of the standard beef breeds. Figures 3 and 4 illustrate the type of steers that have been used.

The 2-year-old beef steer was decided upon as the unit, as (*a*) he seemed to be the unit most used by ranchmen figuring on this question; (*b*) he has about the average capacity for consumption between yearlings, cows, and large steers; (*c*) he is not disturbed, like the heifer, by periods of œstrum or by calving during the trial.[10]

[10] Shepperd, J. H. Carrying capacity of native range grasses in North Dakota. *In* Jour. Amer. Soc. Agron., v. 11, pp. 129–142, figs. 10, pls. 3–5. 1919.

WEIGHING THE CATTLE.

The most important feature of this experiment in relation to the cattle used is that they are weighed at regular intervals and their gains determined in much the same manner as in experimental feed lots. While the total gain of the cattle for the season is the measure of ultimate interest and importance, the gains for various periods of the season are also highly significant. The cattle have been weighed throughout the experiment at the end of regular 30-day periods. Whenever the grazing season has begun before June 1, the cattle have been weighed at the start in May and again on May 31. This has been done in order to make the gains correspond to the months. At the beginning and close of the season the cattle are weighed on three consecutive days and the average of the three weighings determined for the initial and final weights.

FIG. 4.—Two-year-old steers of the type used during the season of 1920. This group was on the rotation pasture.

When the experiment first started the cattle were weighed in two groups for each pasture except the ones on the reserve pasture, which were weighed individually. The cattle of all pastures are now weighed individually. This method of weighing has proved more satisfactory than any other, as the cattle do not become as excited at weighing time. In order to keep a record of the individual steers they are branded with serial numbers.

When the initial weights of the cattle are obtained the steers are divided into groups for the various pastures. The total weights of the different groups are made as nearly equal as possible. The average initial weight for 10 steers has been about 7,500 pounds. In dividing the cattle, attention is also paid to the matter of breeds, the aim being to make as nearly uniform groups for each pasture as possible. The cattle have free access to water at all times and

are not weighed until it has been determined that they have had sufficient water. They are weighed during the same time of day at each weighing. If the weights at the end of any period appear abnormal in any respect, they are checked the following day.

Figure 5 shows the corrals which are used to hold the cattle at weighing time. Figure 6 gives a near view of the rack around the scales. The gates to this rack are operated by means of ropes and pulleys, which greatly add to convenience in weighing the cattle.

GAINS OF THE CATTLE.

The gains of the cattle will be briefly discussed in order to show more clearly the relation between the quantity of native forage available for grazing and its influence upon the seasonable gains of the cattle. When the experiment started it was not definitely known how

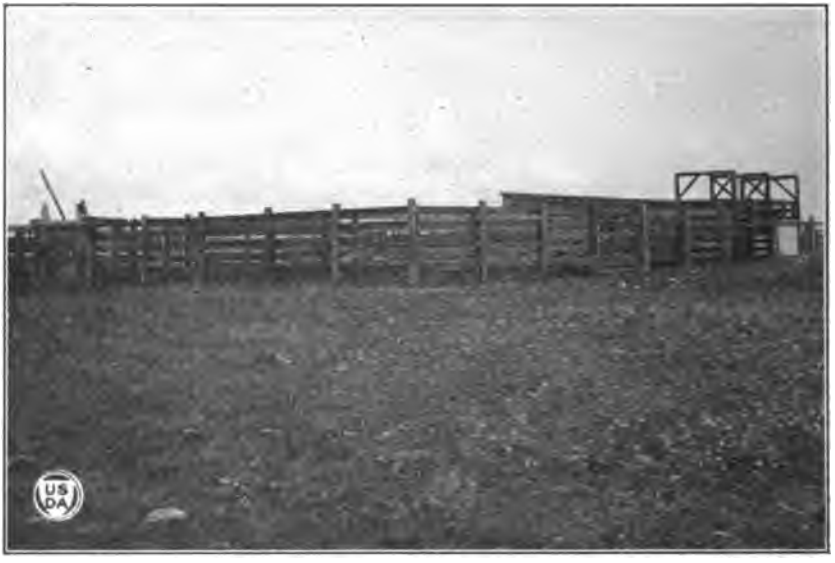

FIG. 5.—Corrals used to hold the cattle at weighing time. The scales are shown at the right.

much gain per head the native forage of this area was capable of producing. The average gains of the cattle for the period the experiment has been in progress are shown in Table 2. It will be noted that the highest gains per head are secured in the 100-acre and the 70-acre pastures. The gains of the cattle in these two pastures are now looked upon as the normal maximum gains per head that may be expected from the native forage. Both of these pastures had abundant feed left standing at the close of each season. Therefore, the quantity of available feed could not have been a limiting factor in the production of gains. This is also further shown by the fact that the gains in these two pastures have been practically equal. The small difference in favor of the 70-acre pasture is considered of minor significance. The gains in the 100-acre pasture may be influenced by its size and also by the fact that through it is the entrance to the

well and all other pastures. The cattle in this pasture are therefore more often disturbed than those in any other pasture, while those in the 70-acre pasture are the least annoyed.

The gains of the cattle in the 50-acre pasture show that they did not have enough feed to carry them through September with full gains. In the 30-acre pasture the cattle did not have sufficient feed to carry them through July with normal gains.

FIG. 6.—A close view of the rack on the platform of the scales. The gates are operated from the outside by means of ropes and pulleys.

TABLE 2.—*Average monthly and seasonal gains of 2-year-old steers, showing the increased weight obtained in the pastures continuously grazed for six years, 1916 to 1921, inclusive, and in the rotation pasture for four years, 1918 to 1921, inclusive.*[1]

Pasture.	Average total gains or losses[2] (pounds).											Average number.	
	Monthly.						Seasonal.[3]						
	May.	June.	July.	August.	September.	October.	Per pasture.	Per head.	Per acre.	Per 100 pounds live weight.	Per head, daily.	Steers per pasture.	Days grazed.
100 acres.....	[4] 347	1,084	628	540	403	47	2,875	287.5	28.6	38.3	1.92	10	150
70 acres.....	[4] 432	1,158	601	573	418	−24	2,942	294.2	42.0	39.1	1.96	10	150
50 acres.....	[4] 388	1,165	593	568	138	−217	2,441	244.1	48.8	32.8	1.65	10	148
30 acres.....	[4] 362	1,088	438	210	[5]−133	[6]−285	1,803	180.3	60.1	24.0	1.63	10	111
Rotation, 70 acres.....	[7] 843	1,364	710	712	314	−41	3,480	267.7	49.7	35.7	1.80	13	149

[1] Part yearlings were used in 1916 and 1918. The gains in the table have been reduced to a 2-year-old basis, differing but slightly from those obtained. When yearlings were used the number of cattle were increased to bring the total initial weight up to about 7,500 pounds.

[2] A minus (−) sign represents a loss.

[3] This average does not equal the sum of the monthly averages because of the nonuniformity of the grazing periods.

[4] Average for three seasons in which the cattle were started on the pastures in May.

[5] Average for parts of month during three seasons.

[6] Loss for one season in which the cattle finished the season on the pasture.

[7] Average for two seasons that the cattle were started on the pasture in May.

The rotation pasture was grazed with the same number of cattle as the other pastures during 1918 and 1919. However, the cattle did not gain as much as those in either the 100-acre or the 70-acre pasture. This was not because of a shortage of feed or a difference in kind of feed, but may be traced directly to the watering facilities, which are not as satisfactory for this pasture as for the others. The cattle each season spend a good deal of time in the lane leading to the water trough. In 1920 the number of cattle in the rotation pasture was increased to 15, and in 1921 to 17. In 1921 this pasture was grazed too close to produce its highest gains per head. From the percentage of the foliage cover removed by grazing in this pasture during 1918 and 1919, it is quite clear that it would have readily supported more cattle. Therefore, the gains produced since the number of cattle has been increased are of more significance than they would otherwise have appeared. The aim in this pasture is to utilize the maximum quantity of vegetation without too greatly reducing the gains per head of the cattle. Since the number of cattle in the rotation pasture has been increased it has produced higher gains per head than either the 50-acre or the 30-acre pasture, with practically an equal utilization of the native vegetation and without injury to it.

During only one year (1916) have the cattle on the 30-acre pasture finished the season on it. The rule that has been followed is to leave the cattle on the pasture until they show a decided loss in weight. This loss has ranged from 25 to 50 pounds per head. Had the quantity of visible forage been used as the measure of the time for their removal, they would have been removed earlier each year. It is always true that the cattle will remain on the pasture for days without loss in weight when they have no apparent forage supply before them. The loss usually comes suddenly and may occur within 5, 10, or 15 days. When the pasture becomes short the cattle are weighed every 5 or 10 days to determine when loss begins. When continual loss in weight is clearly established the cattle are removed to the reserve pasture for the rest of the season.

From Table 2 it will be seen that the cattle on the 100-acre, the 70-acre, and the rotation pastures show either light gains or losses for the month of October and somewhat reduced gains during September. The lowered gains during the latter part of the season do not necessarily condemn fall grazing. This is the time when cattle put on the "finish" so often referred to by stockmen, which is apparently a hardening process brought about through a reduction in the quantity of water that they drink, as well as a change in the condition of their flesh. Therefore, when cattle are without feed or water for 24 hours in the fall they will "shrink" less than they would during the same length of time earlier in the season. The autumn also represents the transition or adjustment period of the cattle between summer and winter. The cooler weather of autumn always causes shrinkage of the cattle, which is recorded as a loss in weight.

During the five years that the steers on the 30-acre field have been removed from their pasture they were on the reserve pasture for an average of 47 days. During this time they made an average total gain of 860 pounds, as compared with 370 pounds for the steers on the 100-acre and 351 pounds for those on the 70-acre pasture. The

gains produced in the latter two pastures during the 47-day period, as compared with the earlier gains, indicate that the fall or mature condition of the vegetation may have a pronounced influence upon the gain. However, the gains made by the steers from the 30-acre field during the same period on the reserve pasture strongly indicate that the condition of the cattle exerts an influence on the gains as great as or greater than that due to the condition of the vegetation. The cattle on the 100-acre and the 70-acre pastures have been on full feed all summer. They have therefore been able to put on the maximum gains which the native vegetation is capable of producing by the time it is fully mature. The steers on the 30-acre pasture, on the other hand, have been forced to graze a short range and have therefore not been able to make the maximum gains which an abundant supply of native vegetation is capable of producing. Therefore, when they obtain full feed in the reserve pasture they are in a condition to put on gains more rapidly than steers that have been on full feed up to that time. The fall gains of these steers are all the more remarkable when it is considered that they are made notwithstanding the general tendency to shrink during cool weather.

PERCENTAGE OF VEGETATION ANNUALLY REMOVED BY GRAZING.

Table 3 shows the estimated percentage of foliage cover annually removed from the different pastures by grazing. The quantity removed is estimated, because any more exact measurement, such as mowing, would disturb the condition of the pasture more than the annual grazing. When no vegetation is removed, as in an ungrazed pasture, there is 100 per cent foliage cover for the season. If all the vegetation has been consumed by the grazing cattle 100 per cent has been removed. Other estimates are based on these two conditions. Plate I shows two conditions of the same area, Figure 1 showing the pasture when it was estimated that 15 per cent of the vegetation had been removed, and Figure 2 the same area later in the season when it was estimated that 65 per cent of the vegetation had been removed. It is recognized that the personal equation influences any estimate, but the fact that the estimates have been made by the same person for the different seasons increases their value. However, the relative quantities are the important factors and show clearly the degree of grazing. In the 100-acre pasture the average proportion of foliage cover that has been removed is 51 per cent. This fact would almost lead one to assume that grazing at the rate of one head to 5 acres would furnish sufficient feed for the season. However, the 50-acre pasture shows that this is not enough, as the cattle lose weight because their feed is gone before the end of the season. The 70-acre pasture, with an annual average of 74 per cent of the foliage cover removed by grazing, has produced sufficient feed to carry the cattle through the season with maximum gains per head. This would strongly indicate that in order to insure sufficient feed and not overgraze under a system of continuous grazing, from 15 to 25 per cent of the foliage cover should remain on the pasture at the close of the season. To make a greater utilization of the forage a different system of grazing must be adopted. Since the number of cattle has been increased in the rotation pasture, over 90 per

cent of the vegetation has been removed by grazing. The gains of the cattle per head have been between those of the steers on the 100-acre and the 70-acre pastures and the two small pastures. The gains of the rotation steers during the past two years have been produced on a basis between 4 and 5 acres per head. The quantity of the vegetation remaining on a pasture at the close of the season indirectly determines its grazing capacity under a system of continuous grazing. However, under a system of deferred and rotation grazing the vegetation remaining on a pasture at the close of the season has no bearing upon its grazing capacity but more nearly determines the utilization of the forage. Under this system a larger percentage of the vegetation can be removed annually without reducing the gains of the cattle to the lowest point and without the injury to the vegetation attendant upon close continuous grazing. From the above facts it is clear that a high percentage of foliage cover removed means a lowered gain of the cattle. One reason why the cattle in the rotation pasture are able to produce higher gains per head on an acreage lower than the 50-acre pasture is because of the advantage derived by the vegetation from the rest periods. Another reason is that the cattle do not have to remain long at a time on a division with a rapidly diminishing food supply.

TABLE 3.—*Estimated percentage of foliage cover annually removed from the different experimental pastures by grazing.*

Year.	Cover removed from pastures (per cent).				
	100 acres.	70 acres.	50 acres.	30 acres.	Rotation (70 acres).
1916	30	50	70	95	.....
1917	40	65	90	100	.....
1918	55	75	100	100	80
1919	55	85	100	100	50
1920	60	85	100	[1] 95	90
1921	65	85	100	[1] 95	95
Average	51	74	93	98	79

[1] Not all *Artemisia frigida* taken.

It has been stated that "the maximum number of cattle that can safely be carried on any square mile of territory is the number that the land will support during a poor season." [11]

The above statement is literally true. From the results of the experiment herein reported it might be more correct to say that "the determining factor is the number of cattle that can be grazed during an average season." During years of very severe drought, such as sometimes occur on the Great Plains, no system of grazing can be expected to furnish feed for the normal number of cattle. It would not be advisable, though, to reduce the number of cattle in all seasons to meet an isolated condition; it is considered advisable, however, to regulate the number of cattle to fit an average season rather than to attempt to adjust the number to fit the varying seasons. Under such an arrangement a season below normal will mean close grazing and

[11] Smith, Jared G. Forage conditions of the prairie region. *In* Yearbook, U. S. Dept. Agr., 1895, pp. 309–324, figs. 70–74. 1896.

FIG. 1.—VIEW ACROSS THE QUADRAT AREA IN THE 100-ACRE PASTURE. JULY 15, 1921.

At this time it was estimated that 15 per cent of the foliage cover had been removed by grazing.

FIG. 2.—SAME AREA SHOWN IN FIGURE 1, PHOTOGRAPHED IN OCTOBER, 1921.

At this time it was estimated that 65 per cent of the foliage cover had been removed by grazing.

FIG. 1.—VIEW ACROSS THE QUADRAT AREA IN THE 30-ACRE PASTURE.

The composition and density of the vegetation are shown as they appeared before grazing in July, 1915.

FIG. 2.—CLOSE VIEW OF THE QUADRAT THAT IS MAPPED IN DETAIL IN THE 100-ACRE PASTURE. JULY, 1915.

reduced gains, while one above normal will produce normal cattle gains and the vegetation will benefit by the lighter grazing. In other words, it is better to regulate the intensity of grazing, so that during good years the vegetation is benefited instead of attempting to consume all the forage by increasing the number of cattle. This is more likely to insure the maintenance of the pasture in a high state of production.

MEASURE OF EFFICIENCY OF A PASTURE OR SYSTEM OF GRAZING.

From Table 2 it will be noted that the steers in the 30-acre pasture have made the highest average total gain per acre. This does not mean that this pasture is the best or that the most desirable grazing system was used there. If the total gain per acre is to be accepted as the sole measure of efficiency of a grazing system, then the 30-acre unit is most efficient for the utilization of the native vegetation. However, since the number of cattle has been increased in the rotation pasture, the total gain per acre produced in that inclosure has been the highest obtained. The rotation pasture has also produced a total and individual gain per acre during the past two years greater than the combined gains of the 50-acre and the 30-acre pastures. The larger gain was produced on fewer acres with a lesser number of cattle. These facts bring out the point that the high gain per acre in the 30-acre pasture has not been obtained because the cattle have done exceptionally well, but because they made 94 per cent of their gain during the first 65 days of the season on a very limited acreage. In doing this they produced the lowest gain per head, however, and were moved to another pasture before the end of the grazing season.

The fact that the steers on the 30-acre field were removed from their pasture as soon as they showed a decided loss in weight has contributed to their high gain per acre. It is obvious that if they had been forced to remain on the pasture long enough the result could easily have been made to equal no gain per acre. Had the cattle continued to lose at the average rate used as the index for their removal, they would have lost the gains made in less time than they were put on. However, it is clear that the rate of loss would have increased during the time they would have been without feed.

From Table 4, which shows the average daily gain per head for the period the steers remained on the 30-acre pasture, it is clear that all other pastures have produced a greater gain. This fact also indicates that the gain per acre alone is not the most dependable index as a measure of a pasture. The purpose of the experiment on this pasture has been to abuse the vegetation by severe grazing and not to produce a high or low gain per acre. This has been accomplished in a very satisfactory manner to date. If the number of cattle had been reduced in order to maintain them on the pasture the full season, the grazing rate would have approached that of some of the other pastures and the purpose would have been defeated.

If a high individual gain per acre is desired regardless of other factors, one must be content with a low gain per head during the early part of the season. If, on the other hand, the maximum gain per head is desired, an essential for the best beef market, the acreage

must be increased so that the cattle will have an abundance of feed before them at all times, and as a result the per-acre gain will be reduced. While a high individual gain per acre might on casual consideration appear to be the most desirable measure of efficiency of a pasture or system of grazing, other factors should not be underestimated. For example, the vegetation in the 30-acre pasture has been injured by the close early grazing. This factor, however, does not lend itself readily to definite measurement, because it is cumulative and may not be apparent until a pronounced reduction has occurred in the grazing capacity of the area. This effect is best determined by the seasonal gains per head of the cattle and the condition of the vegetation. The injury to the vegetation must be given relative consideration with the cattle gains, either per head, total per acre, or individual per acre, in the determination of a measure of efficiency of a grazing system. Another factor of much weight is the time of removal of the cattle from a pasture. A system of grazing that makes it necessary to remove the cattle from a given area by the middle of July or August in order to procure the maximum gain from it is not to be commended. The cattle are not ready or in the best condition for market at this time, nor is it desirable to start them in the feed lot so early in the season. If another pasture is to be provided for them, it would be better to enlarge the first one or reduce the number of cattle and graze it in such a manner as will carry the cattle the full season. This arrangement would also result in better gains per head.

TABLE 4.—*Average daily gains of 2-year-old steers for the period during which the 30-acre pasture was grazed in the years 1916 to 1921, inclusive.*

Year.	Days grazed.	Average daily gains per head (pounds).				
		100 acres.	70 acres.	50 acres.	30 acres.	Rotation (70 acres).
1916	150	1.93	2.08	2.04	1.86	.....
1917	115	2.37	1.98	2.24	1.08	.....
1918	105	2.31	2.44	2.27	1.48	2.11
1919	90	2.55	2.92	2.70	1.99	2.96
1920	90	2.77	2.82	2.41	1.96	2.76
1921	115	2.19	2.42	2.22	1.47	2.18
Average	111	2.35	2.44	2.31	1.64	2.50

In order to determine the most efficient system of grazing it is necessary to formulate a measure by which a pasture can be judged. Such a measure must include all the factors with which the problem of grazing is intimately concerned. If a single measure, such as the gains per head or per acre, is used, other factors which are correlated with it will not be given sufficient consideration. Therefore, the most efficient system of grazing is one that will insure sufficient forage during the entire season to produce the greatest total gain, with the least number of cattle on the minimum unit of land, without permanent injury to the native vegetation. The system of grazing that most nearly fulfills this measure of efficiency may not be the one that produces the maximum gain per head or the greatest individual gain per acre. In order to fulfill its requirements the

greatest total gain per pasture and per acre will be obtained. While the maximum gains per head or per acre may not be the most desirable measure of grazing efficiency, they are essential within certain limits. It is obvious that the number of cattle may be increased until the total gain secured is greater than for any other system of grazing. However, this may be carried to a point where the gains per head may be so reduced that 25 cattle will produce no greater total gain than that produced by 20 head on the same acreage under the same system of grazing.

The measure of grazing efficiency as formulated is not as difficult of attainment as might at first appear. In order to provide the greatest total gain per unit area, the native forage must be allowed to maintain its maximum power of production. Continual close grazing early in the season causes a reduced production of forage. Therefore, the vegetation must have a period of rest and be allowed to mature a crop normally before it is grazed. In order to avoid too greatly reducing the gains per head of the cattle by forcing them to graze a short pasture for a long period, they must be allowed to graze different units for shorter periods. Such a system of grazing will also insure the maximum utilization of the vegetation with the least injury to it. The deferred and rotation system of grazing will come nearer to fulfilling the requirements of the measure of grazing efficiency than continuous grazing on a larger or smaller acreage per head.

BOTANICAL STUDIES IN CONNECTION WITH THE EXPERIMENT.

The first step necessary in connection with this experiment was a complete survey of the native vegetation. Therefore, in 1915 an herbarium was collected, comprising between 275 and 300 species of plants. This has been enlarged during the succeeding years. The plants collected are practically all confined to the highlands or prairie. Of the total number of species from 50 to 60 are grasses. While a comparatively large number of species of plants grow on the prairie, only 25 or 30 are important from the standpoint of grazing.[12] Out of this number four species produce approximately half of the forage.

It was not only necessary to know the individual species of plants, but also to determine their relationship to each other. This phase of the work has been more fully discussed elsewhere.[13]

The vegetation of this section is not as complex as that in some other parts of the Great Plains; for example, at Ardmore, S. Dak. The composition of the vegetation is remarkably uniform throughout the area. This fact tends to minimize complications in recording the effects of grazing.

The composition of the vegetation is very clearly illustrated in Plate II, Figure 1. The season of 1915, when the photograph shown in this illustration was taken, was very favorable, and all plants reached their maximum development.

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[12] Sampson, Arthur W. Important range plants: Their life history and forage value. U. S. Dept. Agr. Bul. 545, 63 pp., 56 pls. 1917.

[13] Sarvis, J. T. Composition and density of the native vegetation in the vicinity of the Northern Great Plains Field Station. Jn Jour. Agr. Research, v. 19, pp. 63–72, 2 figs., pls. 12–14. 1920.

The dominant plant species are *Bouteloua gracilis*, *Stipa comata*, *Carex filifolia*, and *Carex heliophila*.[14] The total basal cover[15] of the vegetation is approximately 60 per cent, which would mean 6 forage acres in every 10. *Bouteloua gracilis* and *Stipa comata* have a basal cover of approximately 20 and 10 per cent, respectively, while that of the two species of Carex combined is less than 10 per cent.

The composition and density of the vegetation are not only highly important in relation to immediate grazing, but also in regard to systems and intensities of grazing. The vegetation on the area selected for the grazing experiment is one of high vegetative development, or the climax type. Grazing on such an area should be so adjusted that the composition and density of this climax type are maintained as nearly as is consistent with the best utilization of the forage. Grazing is necessarily a more or less destructive process, and unless reasonable precautions are taken its effects on a given area are likely to become cumulative and cause serious deterioration of the native range.

In the utilization of lands as grazing areas, the invasion by the higher type of vegetation is often prevented, especially where the species high in the development are grazed with greater relish than those lower in the succession. Thus, the plants well up in the development of the type may disappear gradually or suddenly, according to the degree of disturbance caused by the adverse factor, until the plant stages lower in the development predominate.[16]

The system or intensity of grazing, therefore, that will be best adapted to the type and composition of the vegetation found in this section of the Great Plains is one that will most nearly allow it to maintain its present development and production.

PLANS AND RESULTS OF THE BOTANICAL STUDIES.

In order to determine and follow the effects of different systems and intensities of grazing upon the native vegetation, a definite plan was formulated and has been maintained with slight modification. It was necessary, because of the pressure of other work, to confine the studies to those phases which seemed necessary to a clear understanding of the effects of grazing upon the native vegetation.

The following records have been found most useful in tracing the changes in botanical composition: (1) Mapped quadrats, (2) isolation transects, (3) list quadrats, (4) clipped quadrats, (5) photographs, and (6) general field notes.

MAPPED QUADRATS.

Carefully selected areas were established and charted in 1915. These were located in the open pastures and have been subjected to grazing. Maps (covering a square-meter quadrat) furnish a permanent record of the composition of the vegetation at the beginning of the experiment. They also show clearly the relationship of the different species of plants, especially those that grow in mats, such as the blue grama grass, and those that grow in bunches, like

[14] The "plant formation" of this region is "Mixed prairie." See Clements, Frederic E. Plant Indicators, xvi, 388 pp., 25 figs., 92 pls., pl. A (col.). Washington, D. C. 1920. Bibliography, pp. 364–373. (Carnegie Inst. Wash. Pub. 290.)

[15] Basal cover, as used here, means the extent of ground surface actually covered by plants after the foliage has been removed by grazing or clipping.

[16] Sampson, Arthur W. Plant succession in relation to range management. U. S. Dept. Agr. Bul. 791, 76 pp., 26 figs., 2 pls. 1919.

the western needle grass. They also show to a limited degree the effects of grazing upon the different species. Plate II, Figure 2, and Plate III, Figure 1, show the native vegetation as it appeared on the quadrats in the 100-acre and the 30-acre pastures, respectively, in 1915. Plate III, Figure 2, shows the quadrat in the 30-acre pasture after six years of severe grazing.

While maps have been made to show all species, two charts, Figures 7 and 8, are included, which show only the blue grama and western needle grasses. These are the two most important grasses

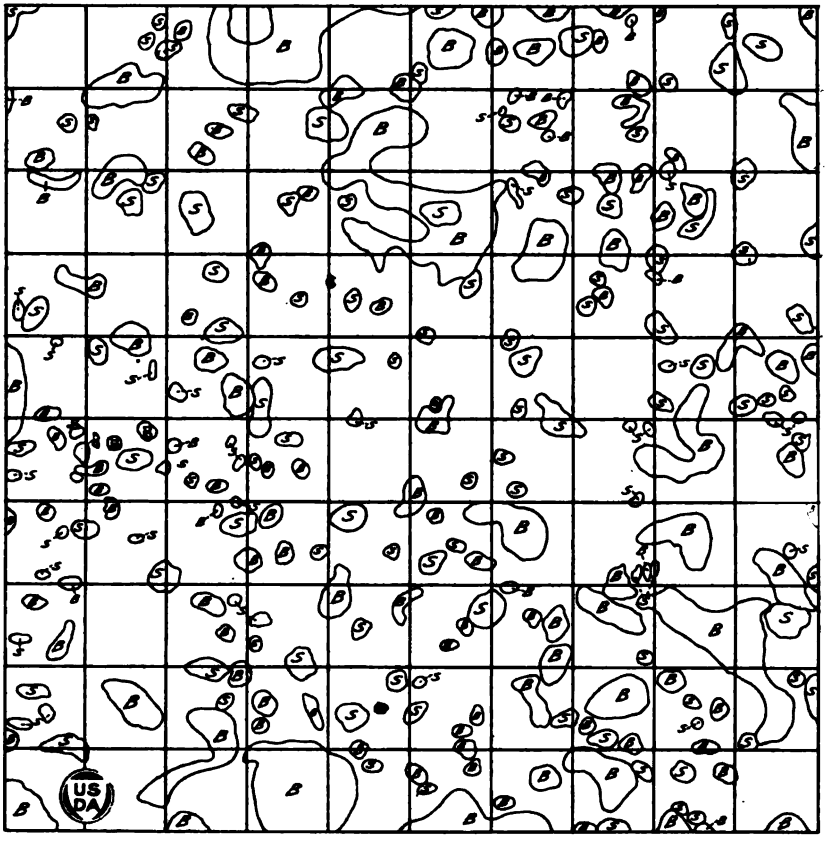

FIG. 7.—Square-meter quadrat in the 100-acre pasture, showing the relationship of Bouteloua and Stipa. Charted near the close of the grazing season in 1916. *Bouteloua gracilis* is indicated by *B* and *Stipa comata* by *S*.

from the standpoint of grazing, since they furnish the largest percentage of the feed. These maps were made in the 100-acre and the 30-acre pastures in 1916 and show the relationship of these grasses before the effects of grazing had become apparent. There is considerable difference noted between the same quadrats mapped in 1916 and 1920.[17] This difference is mainly in the size of the mats of blue

[17] The quadrat maps have been drawn free-hand. In 1918 a pantograph was obtained and tested for charting. However, it has not yet been used for this purpose. Its use in charting has been described by Hill. See Hill, Robert R., Charting quadrats with a pantograph. *In* Ecology, v. 1, pp. 270–273. 1920.

grama grass and the bunches of needle grass. The larger mats and bunches have broken up since 1916. The dry seasons have no doubt been of greater influence as a direct cause of this than has the grazing in the case of blue grama. Western needle grass has been greatly reduced in extent in the quadrat in the 30-acre pasture. This has no doubt been largely because of the intense grazing, since the reduction is twice as much as in the quadrat in the 100-acre pasture. This fact is further confirmed by observation and by the clipped quadrats. Western needle grass does not withstand severe grazing as well as

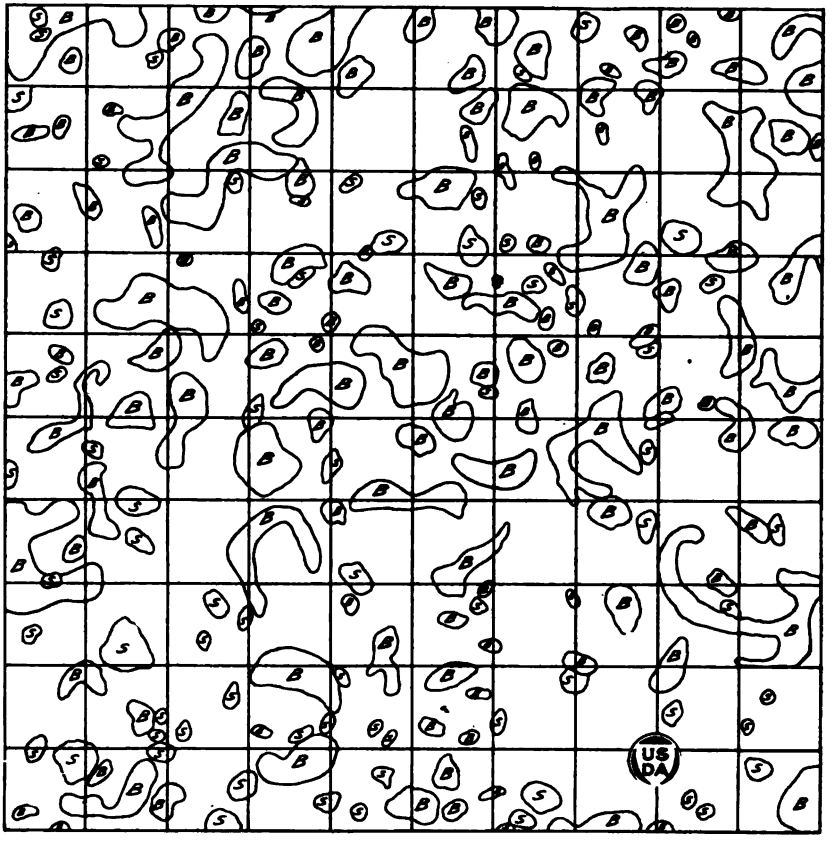

FIG. 8.—Square-meter quadrat in the 30-acre pasture, showing the relationship of Bouteloua and Stipa. Charted near the close of the grazing season in 1916. *Bouteloua gracilis* is indicated by *B* and *Stipa comata* by *S*.

blue grama. It is a shorter lived perennial and is more dependent upon reseeding. Western needle grass is the species that is benefited most by the system of deferred and rotation grazing.

ISOLATION TRANSECTS.

Areas that are now known as "isolation transects"[18] were set aside in the 100-acre and the 30-acre pastures in 1915. A similar area

[18] Dr. H. L. Shantz suggested these areas when he visited the station in 1915. Their designation as isolation transects was suggested by Dr. F. E. Clements when he visited the station in 1917.

was also set aside in one division of the rotation pasture in 1918. When the experiment was started the value of these transects was underestimated. It was not until 1919 that their real worth was appreciated. In Figure 9 is shown a diagram of one of these transects. The transect is 300 feet long; the units are each 20 feet square. One of the units in series A is opened to grazing each year,[19] while one of the units in series C is closed to grazing at the same time. Series B is not subject to grazing at any time, nor is the vegetation removed in any manner.

In the 30-acre pasture the isolation transect shows the points of most interest and significance in regard to the development of *Artemisia frigida*. In series A it is becoming thicker in the unit opened to grazing in 1918. The growth of this species in series B is no different from that in the 100-acre pasture. The maximum development of *A. frigida* is shown in series C, the units closed to grazing annually. The plants in the unit closed in 1918 are not greatly different from those in series B. The 1919 unit shows a slight increase in the number of plants, but they are about normal in size. The units closed in 1920 and 1921 show a greater increase in the number of plants and a pronounced increase in the vigor of the individual plants. Plates IV and V illustrate the difference in the thickness of the plants and their vigor. The photographs of the isolation transect in the 30-acre pasture, reproduced in these plates, show the effects of intense grazing for varying periods upon the native vegetation better than it can be recorded in any other way.

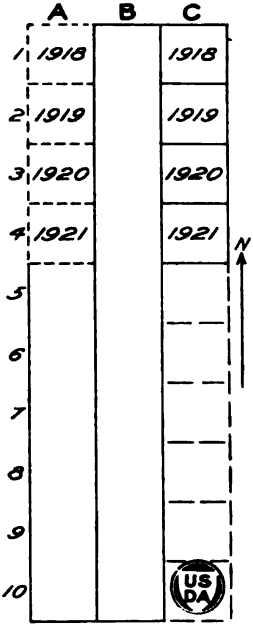

FIG. 9.—Diagram showing plan of isolation transects: *A*, Grazing series, one unit opened to grazing each year; *B*, permanent series, units never grazed; *C*, regeneration series, one unit closed to grazing each year. Solid lines show fences, dotted lines where fences formerly stood, and dash lines where fences will ultimately be built.

LIST QUADRATS.

List quadrats, square-meter areas in which the plants are counted and the numbers recorded, are of value in keeping a record of the number of plants of individual species. Their value is increased, since it is possible to include a comparatively large number of square-meter quadrats. These quadrats are located in the open pastures and in the isolation transects. They are permanently located by means of a single stake. There are 40 of these quadrats in each pasture. The highly important species are also recorded in an equal number of duplicate quadrats cornering the originals. It is possible to keep a record of individual species which appear as single plants or as single distinct bunches, such as *Aristida longiseta* or *Koeleria cristata*. Not all of the species that appear in the quadrats are recorded. The species that are regularly listed have been reduced

[19] Units were opened on the north end and closed on the south end in 1917. In 1918 they were placed across from each other.

to approximately 10 in number. Only those species that are the most abundant or significant are recorded, but the same ones are listed in all the quadrats. Out of the number that have been listed, three species stand out as of primary significance. These are *Artemisia dracunculoides*, *A. gnaphalodes*, and *A. frigida*. Of these *A. frigida* is of greatest importance, because it is an indicator of overgrazing [20] and because the cattle refuse to eat it until they are forced to do so. During the past two years the cattle in the 30-acre pasture have lost weight, while many of these plants were still standing in the pasture. Plate VI shows how many of these plants were left in the 30-acre pasture at the close of the grazing seasons of 1917 and 1921. From Figure 1 of this plate it will be noted that practically all plants were eaten in 1917, while Figure 2 shows numerous plants of *A. frigida* still standing at the close of the season in 1921. The cattle do not seem to hesitate about eating the other two species of Artemisia, though they do not take them as readily as most of the grasses. They begin to eat *A. frigida* when other feed becomes scarce in the small pasture. It is usual to see scattered over the pasture the stalks of this plant that the cattle have pulled off and spit out. This sage is bitter and distasteful to them and is therefore avoided. Plate VII illustrates the condition of the 30-acre pasture on July 15, 1919, and on the same date in 1921. The photographs here reproduced were taken at the time the cattle usually begin to eat *A. frigida* and afford a very clear idea of the effects of continuous overgrazing in relation to this species of sage. The dark plants in Figure 1 are *A. dracunculoides*. It will be noted that none of these plants can be seen in Figure 2.

TABLE 5.—*Number of plants of Artemisia frigida per square meter in 16 quadrats in the 100-acre and 30-acre pastures in 1915 and in the same square meters in 1920.*[1]

100-acre pasture.		30-acre pasture.		100-acre pasture.		30-acre pasture.	
1915	1920	1915	1920	1915	1920	1915	1920
10	3	0	4	0	1	0	5
2	1	0	1	0	0	3	8
4	11	0	1	0	0	2	4
9	3	2	4	3	1	0	5
2	0	0	8	3	1	0	6
1	1	0	3	1	2	3	10
4	5	0	2	0	0	3	6
10	6	4	11				
2	1	0	7	51	35	17	85

[1] These 16 square meters are not included in the 40 list quadrats previously discussed.

A. frigida (pasture sage) has increased about five times per unit area in the 30-acre pasture since the experiment started. There has been an increase not only in number but also in the size of the individual plants. Plate VIII, Figure 1, illustrates clearly the size a single plant may attain. The increase in number is best shown by Tables 5 and 6. In both the 100-acre pasture and the 30-acre pasture 16 quadrats were permanently located in 1915. They formed areas

[20] Shantz, H. L. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. Dept. Agr., Bur. Plant Indus. Bul. 201, 100 pp., 23 figs., 6 pls. 1911.

FIG. 1.—CLOSE VIEW OF THE QUADRAT THAT IS MAPPED IN DETAIL IN THE 30-ACRE PASTURE. JULY, 1915.

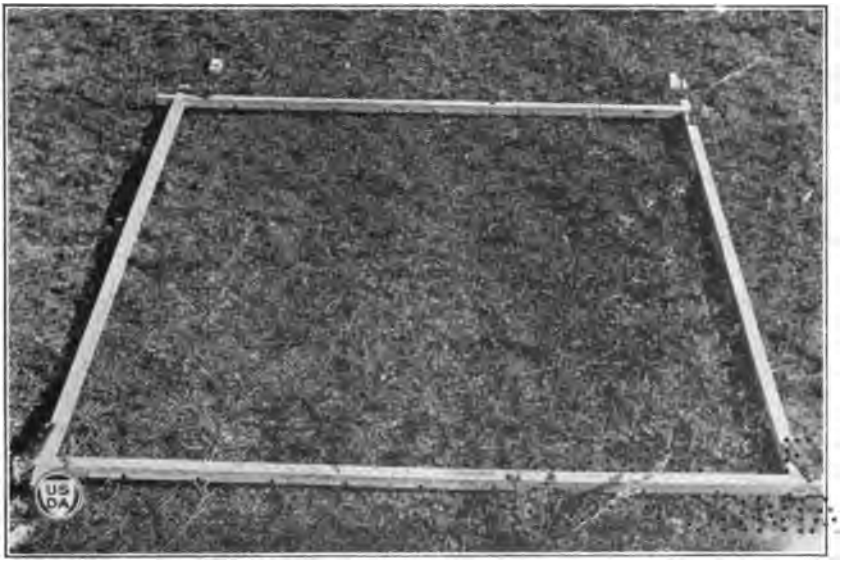

FIG. 2.—SAME QUADRAT SHOWN IN FIGURE 1, PHOTOGRAPHED IN OCTOBER, 1921, AFTER SIX YEARS OF SEVERE GRAZING.

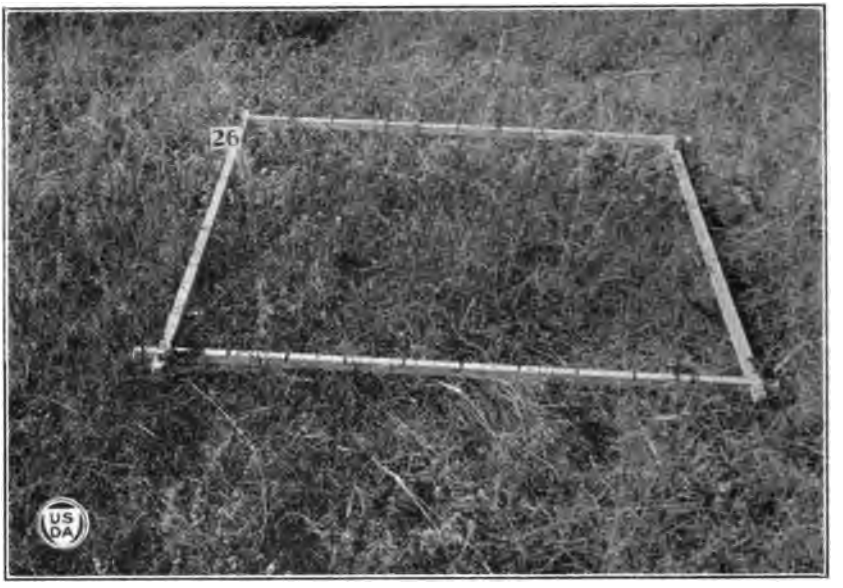

FIG. 1.—UNIT IN THE 30-ACRE PASTURE CLOSED TO GRAZING IN 1918.

Note the plants of *Artemisia frigida*, which are about normal in size and number. The top of the frame in each case marks the division between the closed units and those never grazed. October, 1921.

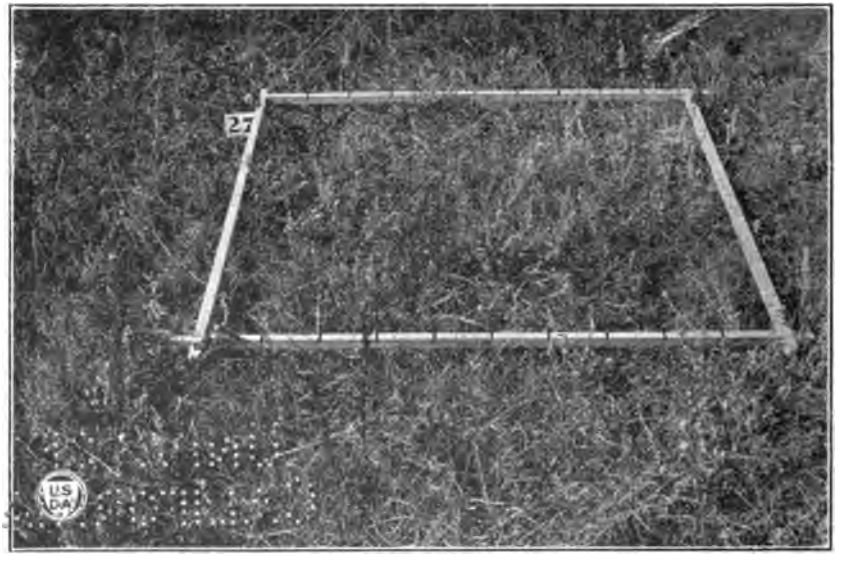

FIG. 2.—UNIT IN THE 30-ACRE PASTURE CLOSED TO GRAZING IN 1919.

Note the plants of *Artemisia frigida*, which are about normal in size but somewhat thicker on the ground than those shown in Figure 1. October, 1921.

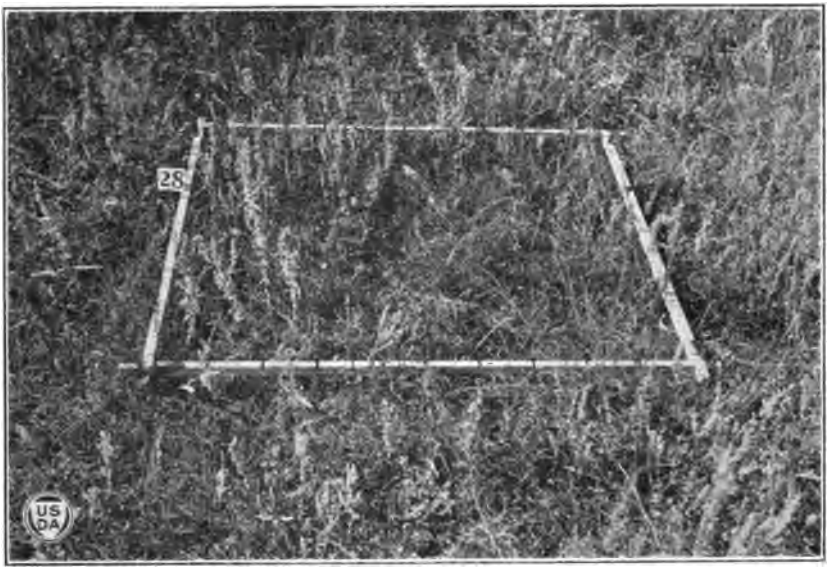

FIG. 1.—UNIT IN THE 30-ACRE PASTURE CLOSED TO GRAZING IN 1920.

Note the plants of *Artemisia frigida*, which are taller and more numerous than in the units closed in 1918 and 1919. October, 1921.

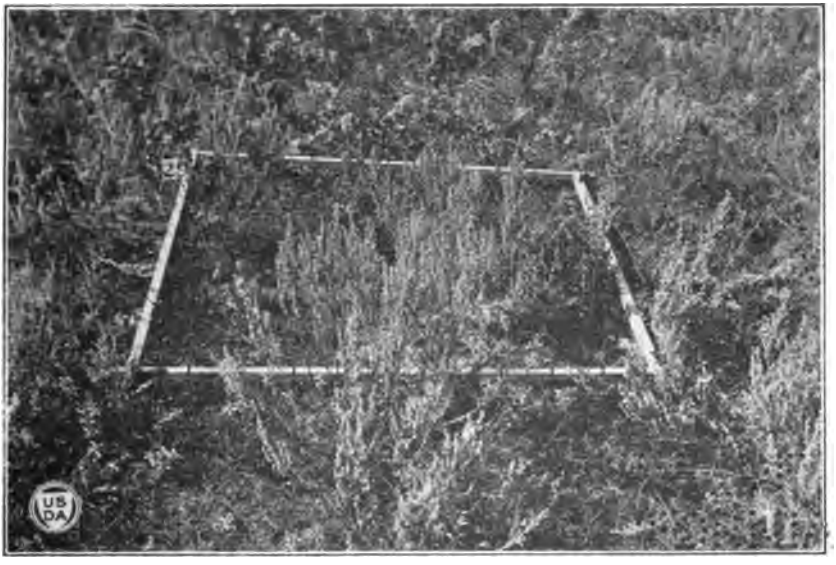

FIG. 2.—UNIT IN THE 30-ACRE PASTURE CLOSED TO GRAZING IN 1921.

Note the plants of *Artemisia frigida*, which are much larger, coarser, and thicker on the ground than in the units closed during the previous seasons. October, 1921.

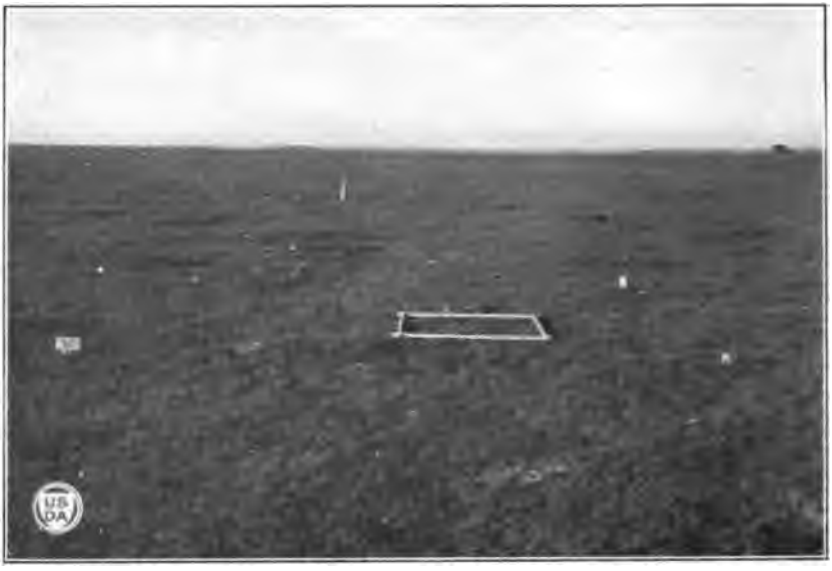

FIG. 1.—VIEW ACROSS THE QUADRAT AREA IN THE 30-ACRE PASTURE AT THE CLOSE OF THE GRAZING SEASON IN 1917.

Note that practically no vegetation is left standing. November, 1917.

FIG. 2.—SAME AREA SHOWN IN FIGURE 1, PHOTOGRAPHED AT THE CLOSE OF THE SEASON IN 1921.

Note that a considerable number of plants of *Artemisia frigida* are left standing. October, 1921.

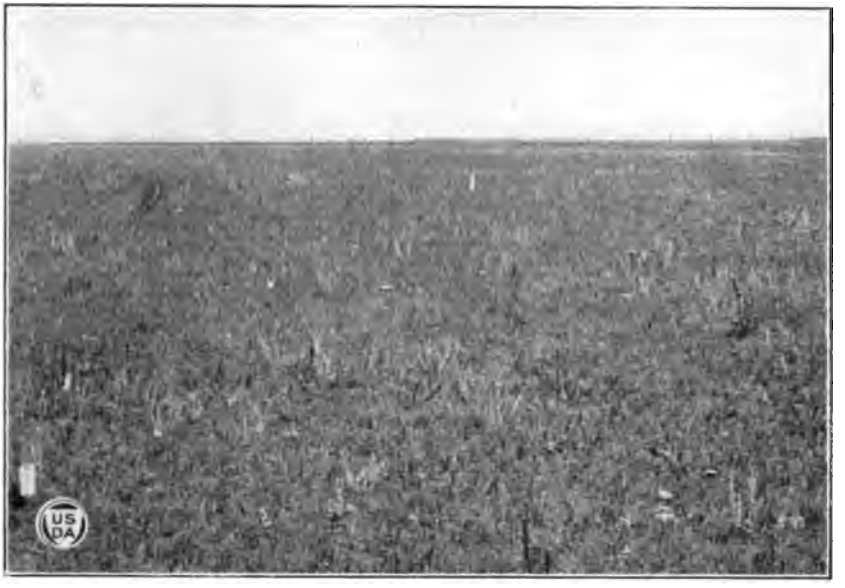

FIG. 1.—VIEW ACROSS THE QUADRAT AREA IN THE 30-ACRE PASTURE, SHOWING ITS CONDITION IN JULY, 1919.

Note that a considerable number of plants of *Artemisia frigida* are left standing and also some *Artemisia dracunculoides* (the dark plants). July 15, 1919.

FIG. 2.—SAME AREA SHOWN IN FIGURE 1, PHOTOGRAPHED IN 1921.

Note the large quantity of *Artemisia frigida*. The cattle usually begin to eat it by the middle of July. *Artemisia dracunculoides* does not appear at this time. July 15, 1921.

FIG. 1.—CLOSE VIEW OF A SINGLE PLANT OF ARTEMISIA FRIGIDA IN THE 30-ACRE PASTURE.

This plant was 10 inches tall and had 36 flower stalks. This affords an idea of the size a single plant may attain. June, 1920.

FIG. 2.—VIEW OF THE CLIPPED QUADRATS IN THE ISOLATION TRANSECT OF THE 100-ACRE PASTURE.

The quadrat cut every 10 days is in the foreground. The duplicates are on the left. October, 1919.

VIEW IN A PASTURE ADJOINING THE NORTHERN GREAT PLAINS FIELD STATION.

The white plants are *Artemisia frigida*, which have been favored by the heavy grazing in this pasture. July, 1915.

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4 meters square, and the number of plants of *A. frigida* in each square meter was listed in 1915 and 1920. The results are presented in Table 5. This table shows that there has been a heavy increase of this species in the 30-acre pasture. The slight decrease in the 100-acre pasture is not great enough to be of any particular importance. There will be found a fluctuation in number from year to year, as some plants die normally, while others meet with accidents, such as being cut off by gophers or pulled up by the cattle. Under normal conditions a few new plants will be established each year, so that the total number remains about the same. However, as soon as some disturbing factor enters, such as the continuous intense grazing of the 30-acre pasture, this is the plant that is ready to take advantage of the weakened condition of other species.

Table 6 shows the number of plants of *A. frigida* in the units of the isolation transects. These show very clearly the effects of grazing upon this species. In the 100-acre transect practically no difference between the different units appears, but in the 30-acre transect there is a striking difference that can be accounted for only by overgrazing. The units that are annually closed to grazing contain the largest number of plants. The individual plants in these units also show pronounced differences, depending upon the length of time the unit has been closed. Table 7 presents these differences clearly.

TABLE 6.—*Number of Artemisia frigida plants per square-meter quadrat in the isolation transects in the 100-acre and 30-acre pastures in 1921.*

[Series A was fenced in 1915; the units are opened in succession to grazing, beginning with unit 1 in 1918. Series B is permanently closed to grazing. Series C is open to grazing except as the units are closed in succession, beginning with unit 1 in 1918.]

Pasture.	Series.	Number of plants per square meter.										
		Unit 1.	Unit 2.	Unit 3.	Unit 4.	Unit 5.	Unit 6.	Unit 7.	Unit 8.	Unit 9.	Unit 10.	Total.
100-acres	A	1	2	1	8	9	2	0	5	0	2	30
	B	5	11	5	5	6	0	2	1	0	2	37
	C	3	5	4	3	13	5	2	1	2	2	40
												107
100-acres (duplicate)	A	1	4	3	1	1	0	1	1	0	1	13
	B	5	3	0	11	5	3	5	2	3	0	37
	C	2	7	4	1	11	4	12	5	4	1	51
												101
30-acres	A	21	7	7	1	2	1	0	1	0	0	40
	B	1	5	3	1	2	0	0	3	0	1	16
	C	5	11	7	25	9	12	7	14	12	11	113
												169
30-acres (duplicate)	A	29	14	32	4	2	1	1	0	0	1	84
	B	0	1	2	0	2	0	3	5	0	1	14
	C	6	23	30	24	16	11	6	6	10	9	141
												239

From Table 7 it is very evident that not only the number of plants is influenced by overgrazing, but also the size of the plants, which is a good index of their physiological vigor.[21] This condition is brought about by reduction of the competition of other species. The vigor of the other species has been reduced by the continuous severe grazing, while the *A. frigida* has been favored, because the cattle do not like it and will not eat it until forced late in the season after it has had a chance to make its normal growth. Since the other species of

[21] Sampson, Arthur W. Plant succession in relation to range management. U. S. Dept. Agr. Bul. 791, 76 pp., 26 figs., 2 pls. 1919.

plants do not have a chance to make much growth, they do not use much of the soil moisture. Therefore, because *A. frigida* is left undisturbed until late in the season it has the advantage of nearly all the moisture available in the soil. It has increased in extent until the cattle will not clean up all of it before they lose weight. In the unit closed in 1918 the competition of other species had not been greatly reduced and the plants of *A. frigida* are in about a normal condition of growth. The competitive influence of other species has not been of much consequence in the units closed in 1920 and 1921. The increase in the number and the size of the individual plants has enlarged the area occupied by *A. frigida* in the 30-acre pasture about 10 times. It can thus be readily seen how this one plant can materially reduce the grazing capacity of a pasture.

TABLE 7.—*Average height, number of stalks per plant, and number of plants of Artemisia frigida per square meter in the units closed to grazing each year in the isolation transect in the 30-acre pasture.*

[Measurements made in the autumn of 1921.]

Year closed to grazing.	Average of 2 square-meter quadrats.		
	Height of plants.[1]	Stalks per plant.	Plants per square meter.
	Millimeters.	*Number.*	*Number.*
1918	177.5	5.9	5
1919	196.4	7.9	16
1920	289.6	8.0	18
1921	295.9	8.7	23

[1] Plants less than 50 millimeters in height were not included.

In 1920 the difference in the size of the plants of *A. frigida* was noted in the various pastures. Measurements were made of all the plants over 25 millimeters in height in the list quadrats. The results obtained are presented in Table 8.

TABLE 8.—*Average height, diameter, and number of stalks per plant of Artemisia frigida in the different pastures in 1920.*

Artemisia frigida.	Pastures.			
	100 acres.	70 acres.	50 acres.	30 acres.
Height of plants.....millimeters..	133.9	127.3	115.1	180.2
Diameter of stalks.....do....	15.2	15.4	13.4	18.1
Number of stalks.....per plant..	6.5	5.3	5.2	7.4

It will be noted that the plants in the 30-acre pasture are the largest in all cases, while those in the 50-acre pasture are the smallest, no doubt because the cattle in the latter pasture have so far been able to graze this plant enough to retard its most active stage of development. Therefore, it does not have the advantage over other species that it has attained in the 30-acre pasture. The cattle have remained on the 50-acre pasture longer during the season, and this fact has allowed them sufficient time to remove the plants gradually. The intensity of grazing also has its effect upon these plants, as the cattle have more feed before them. Therefore, the

other species are not so rapidly exhausted and the cattle are not forced to take the *A. frigida* all at once without access to anything else. The coarseness of the plant in the two pastures also influences its being eaten by the cattle. It seems the intensity of grazing in the 30-acre pasture early in the season is so severe that the *A. frigida* has been able to reach its highest degree of noxiousness, while in the 50-acre pasture the grazing has been just severe enough to keep it from reaching its stage of greatest activity and actually to weaken it. In the larger pastures this species has not been influenced by the grazing. The same general conditions of growth held true for *A. frigida* during 1921 as in 1920, but no measurements were made in the open pastures.

A. frigida spreads and increases by seed. Even when it appears that all vegetation has been removed by grazing, a few stalks of this plant are still found in the pasture. Each plant produces a large number of very small seeds, which are scattered over the ground, and some of them will become established wherever the conditions are favorable. The most favorable places for them to start are along old trails, on old gopher mounds, along old furrows, or on ground that has been trampled by cattle. They are therefore able to establish themselves in any place where some disturbing influence has reduced competition. The intense grazing and consequent heavy trampling of the cattle in the 30-acre pasture therefore afford an advantageous condition for the establishment of seedlings of *A. frigida*.

Another advantage that *A. frigida* has over other species is its ability to assume the nature of a shrub.[22] All the stalks do not die down to the crown each year. Some of them develop green leaves and shoots directly on the old stems early in the season and are therefore able to start the manufacture of plant food at once. Not all of the plants do this, but a number of them do. This early development of green leaves gives *A. frigida* an advantage which the other species do not possess. As far as has been observed all the other species that are common in the pastures die back to the ground each year, and new shoots develop directly from the crown.

In the case of the two other sages, *A. dracunculoides* and *A. gnaphalodes*, very few seed stalks are allowed to develop in the small pastures. The cattle will eat them long before they will touch *A. frigida*. However, in the 100-acre and the 70-acre pastures the three sages are usually not much disturbed by the cattle. The plants have not made unusual abnormal developments in these pastures. *A. dracunculoides* and *A. gnaphalodes* appear abundant and well developed each year, but there has not been an unusual increase in the number per unit area. They are, however, rather coarse and for that reason are avoided by the cattle during the latter part of the season. These two sages are therefore somewhat favored by light grazing. However, they do not seem to be able to take advantage of their strengthened condition, as *A. frigida* does in the case of heavy grazing. The latter species bears much the same relation to grazing in this area that snakeweed does to grazing in the Southwest.[23]

[22] This fact has been observed by Dr. H. L. Shantz in other parts of the Great Plains.

[23] Wooton, E. O. Factors affecting range management in New Mexico. U. S. Dept. Agr. Bul. 211, 39 pp., 3 figs., 9 pls. 1915.

Here on the prairie under light or moderate grazing the "weeds" (species other than the grasses and sedges) bear much the same relation to the intensity of grazing as they do in the bluegrass pastures of the South [24] except that they do not crowd out the more valuable species. It is therefore better to follow a system of grazing that will keep the weeds down and at the same time not allow any of them an opportunity to become noxious because of overgrazing. The 50-acre pasture so far has been able to do this, but the gains per head of the cattle have been somewhat reduced, as the pasture becomes very short toward the close of the season. The rotation pasture is able to accomplish the same results on a slightly reduced acreage and at the same time produce a higher gain per head.

CLIPPED QUADRATS.

The clipped quadrats were established in 1917. The vegetation is cut, or clipped, close to the ground with a pair of roaching shears. It is clipped uniformly closer than it would be grazed by cattle, but care is taken not to destroy the plant crowns. This method of quantitative determination was adopted to secure data on the period of most active growth of the different species and to determine the effect on subsequent growth of frequent removal of the vegetation.

Clippings have been made after 10, 20, 30, and 40 day periods, and also at the end of the season (annual). In 1919 a set of quadrats was added to include the biennial removal of the vegetation. During the same year was added a series of clipped quadrats which are cut in relation to the deferred and rotation system of grazing. The data from these are not included, as the quadrats are not old enough to be of more than minor significance. Duplicate square-meter quadrats were used. The arrangement of the quadrats and their appearance at the close of the grazing season in 1919 are shown in Plate VIII, Figure 2. The quadrats are located in the isolation transect of the 100-acre pasture and are therefore not disturbed by grazing.

It is recognized that there are individual differences between the quadrats. However, they are not great enough to overcome the effects of different intensities of clipping or to obviate the original conception of this method of analysis. The quadrats were clipped for the first time in June, 1917. The vegetation was removed from all quadrats on the same date. The vegetation on them had not been disturbed since 1915 and was only lightly grazed during that season. The total vegetation from each quadrat was weighed (in grams) both green and after becoming air dry. The weights from all quadrats ranged from 235 to 263 grams green and from 168 to 186 grams dry. This included all old growth along with that of the current year. The subsequent clippings have been divided, as shown in Table 9, into the individual dominant species and into other important groups at the time of cutting and weighed both green and dry. Pertinent notes were made of the stage and quantity of growth of all species.

The periods for clipping are now fixed, so that May 1 is considered the date from which all periods start each season. For example, the first clipping is made on May 10 for the 10-day periods, May

[24] Carrier, Lyman, and Oakley, R. A. The management of bluegrass pastures. Va. Agr. Exp. Sta. Bul. 204, 18 pp., 8 col. figs. 1914.

20 for the 20-day periods, etc. The "annual" is fixed at September 1, as there is very little growth after that date. In no season since these quadrats were started have the 10, 20, and 30 day quadrats made enough growth to afford vegetation for clipping at all possible periods. This has been largely because of drought.

Figure 10 shows in graphic form the periods of growth for the different species and groups. The 30-day period was selected for this study, as it represents each of the four months of the season and also corresponds to the weighing dates of the cattle. Bouteloua presents the most uniform line, showing that this species produces a

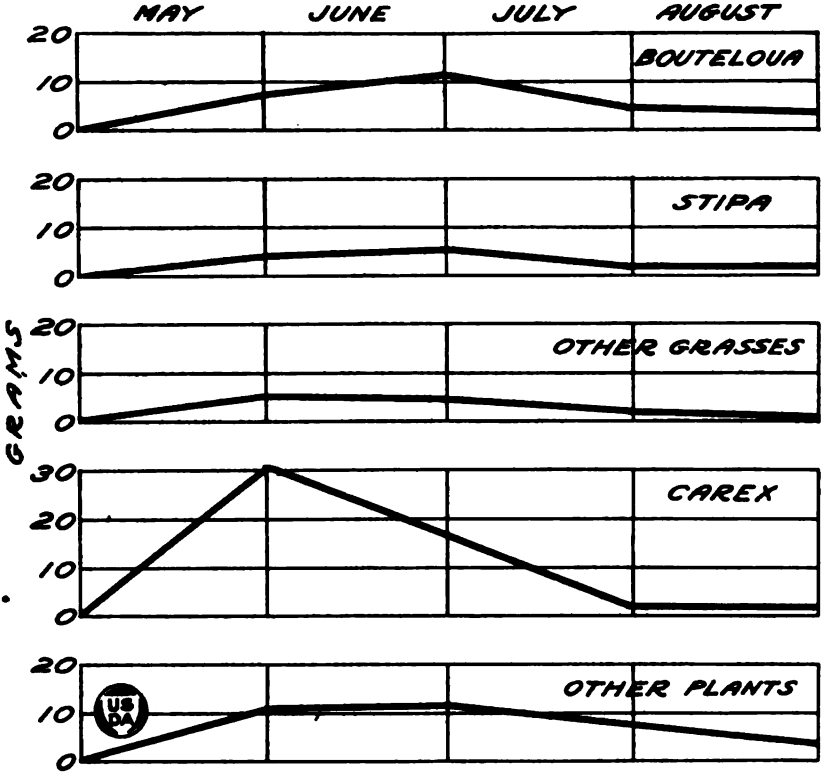

FIG. 10.—Diagram showing the average quantity of vegetation produced by different species and groups of plants at the end of 30-day periods for the period from 1917 to 1921, inclusive. The lines represent the green weight of the vegetation in grams per square-meter quadrant.

fairly uniform growth throughout the season. This is one of the reasons why it is such a valuable grass for grazing. Both Stipa and other grasses also produce fairly uniform lines, but their production is very light toward the close of the season. In the case of the two species of Carex there is a pronounced abundant early growth. *C. filifolia* is one of the earliest plants to mature. It sheds its seeds usually late in May and does not make much growth after that time. *C. heliophila* is not quite as early in maturing and makes more growth later in the season. The two species are shown together, but beginning in 1919 they were separated for the above reasons. In the

case of the "other plants," which include all other species, the curve is fairly uniform for the season. The diagram plainly shows that the period of most active growth, and therefore greatest production of the vegetation as a whole, is during May and June. This period corresponds to the period of the largest gains of the cattle.

In Table 9 are presented the average weights (in grams) for the different intensities of clipping. It will be noted that the totals for the 10-day and 20-day quadrats average very close to each other. This will also be observed for the 30-day and 40-day quadrats. Therefore, it would be possible to drop one of each pair and still retain practically the full value of the data.

The annual quadrats have a lesser total green weight than some of the others but a higher dry weight. This is to be expected, as many of the species are practically dry when cut. Bouteloua and the two species of Carex have produced lesser quantities in the annual quadrats than in any of the others. This may be accounted for in large part because of actual loss through drying. Since the two species of Carex mature early, they are much overripe by September, and part of the stems and leaves is lost by being blown away or dropping to the ground. This fact is only partially true for Bouteloua. The tips of the leaves dry up and may break off, but they are usually green below at this time. It has been noted from observation, and the clipping data confirm it, that Bouteloua is the one species that is benefited by frequent grazing or by clipping. This does not mean that it is impossible to injure this grass by overgrazing, but that it will permit severe grazing longer than any other species and that its growth is stimulated by moderate grazing. The same is true to a lesser degree for the two species of Carex. In the 10-day quadrats practically all that is now left are Bouteloua and Carex, and they have been weakened.

Table 9 shows that Stipa runs low in all quadrats up to the annual ones. From the data and observations of the biennial quadrats as compared with the ones cut annually there are indications that this species is weakened by even the annual cutting. However, as will be noted in Table 9, it is still producing fairly high in the annual quadrats. Stipa has disappeared from the different quadrats in direct relation to their frequency of clipping. The quantity produced was less than before in 1919 in the 10-day and 20-day quadrats, was practically nothing in 1920, and in 1921 there was none in the 10-day and only a trace in the 20-day quadrats. The 30-day quadrats in 1919 produced over 19 grams dry weight; in 1920, 0.65 gram; and a trace in 1921. The monthly removal of the vegetation by clipping and the weakening effect of it have been observed elsewhere.[25] In the 40-day quadrats the quantity was greatly reduced in 1920 and 1921, but they are still producing a light growth. The clipped quadrats show clearly and support the general observation that *Stipa comata* is more susceptible to a reduction or complete extinction by intense clipping or grazing than any other important species at this point. As previously noted, this species has been greatly reduced by severe grazing in the 30-acre pasture. Hardly a stalk of this grass has been allowed to mature normally in the 30-acre or the 50-acre pasture since 1916. The closed units of the isola-

[25] Sampson, Arthur W. Range improvement by deferred and rotation grazing. U. S. Dept. Agr. Bul. 34, 16 pp., 5 pls. 1913.

tion transect in the 30-acre pasture show that Stipa is becoming increasingly slower in producing seed stalks after protection from the hard grazing. This point was brought out in the past two years, and it is not yet clear how long it will take for this grass to reach a stage of normal seed production after it has been subjected to severe continuous grazing.

TABLE 9.—*Average quantity of vegetation produced annually by different species and groups of plants on the quadrats clipped at different intervals, in the 5-year period from 1917 to 1921, inclusive.*

Species or group.	Weight of vegetation per square-meter quadrat clipped at stated intervals (grams).[1]									
	10 days.		20 days.		30 days.		40 days.		Annual.	
	Green.	Dry.	Green.	Dry.	Green.	Dry.	Green.	Dry.	Green.	Dry.
Bouteloua gracilis	25.9	14.9	24.6	14.7	27.4	16.7	23.1	15.4	14.9	12.7
Stipa comata	5.3	3.1	6.8	4.2	13.1	8.0	12.8	8.0	35.8	29.8
Bouteloua gracilis and Stipa comata	31.2	18.0	31.4	18.9	40.7	24.7	35.9	23.4	50.7	42.5
Other grasses	8.8	4.4	8.1	4.4	11.9	6.6	14.0	7.8	6.4	5.0
Total, all grasses	40.0	22.4	39.5	23.3	52.6	31.3	49.9	31.2	57.1	47.5
Carex filifolia and Carex belli-ophila[2]	34.2	17.1	40.8	21.1	51.6	26.9	45.2	25.2	19.2	16.6
Other plants	31.1	9.9	29.8	9.0	32.6	11.1	47.5	16.5	44.6	22.2
Total, all species	105.3	49.4	110.1	53.4	136.6	69.3	142.6	72.9	120.9	86.3

[1] Grams per quadrat can be converted to pounds per acre by multiplying by the factor 8.922.
[2] These have been separated since and including 1919.

The "other grasses" of Table 9 show an apparent reduction in the annual quadrats. A grass that makes up a large percentage of these is *Koeleria cristata* (prairie June-grass). This species is the earliest grass to mature on the prairie. It is usually mature and starts to dry up before the end of June. It, however, makes some secondary growth in the fall. The grasses of this group that appear in the quadrats in their order of abundance are *Koeleria cristata*, *Aristida longiseta*, *Muhlenbergia cuspidata*, and *Agropyron smithii*.

The "other plants" shown in Table 9 are composed of species that appear in the quadrats that do not belong in any other division. The most abundant and important ones are *Artemisia gnaphalodes*, *A. dracunculoides*, *A. frigida*, *Solidago pulcherrima*, and *Psoralea argophylla*. *Artemisia gnaphalodes* makes more rapid and frequent recovery from clipping than the other species, and *Psoralea* the least. When *Psoralea* is cut once or twice early in the season it does not usually make much more growth that year. The "other plants" contain the highest percentage of water, as may be observed from the weights obtained.

There is nothing of particular significance in Table 9 in regard to the yield of "other plants." There are indications that the quantity has been reduced in those quadrats that are frequently clipped. This point is confirmed by observation and by the yearly data. It will be noted that the dry weight for "other plants" is much greater in the annual quadrats than in any of the others. This is true for two reasons: (1) Because the plants cut during the early part of the

season contain a high percentage of water and (2) because of the greater growth of the plants during the entire season.

The clipped quadrats have clearly answered the questions in regard to the period of most active growth and the effects of frequency of removal of the vegetation upon the various species. In addition, they furnish a basis from which to estimate the total quantity of vegetation annually produced.

PHOTOGRAPHS.

Photographs have been taken regularly in connection with the grazing experiment each year, beginning with 1915. The same views have been taken each year, so that certain photographs are directly comparable for a series of years. One set that has been taken in each pasture shows a general view of the quadrat area (an area 4 meters square in which the mapped quadrat is located) and a closer view of the quadrat that is mapped in detail. Starting in 1919, two sets of photographs giving a general view of the quadrat area have been taken each season. One set is taken about midsummer or early in July, the other at or near the close of the grazing season. The early set was added after the *Artemisia frigida* began to be conspicuous in the 30-acre pasture. This set of photographs shows the general condition of all pastures at the time when the vegetation is producing its maximum growth.

Photographs are of unusual value in connection with studies of this nature, as they bring out points and illustrate features that do not lend themselves readily to description or measurement. Photographs also produce a permanent record that can not be obtained in any other manner or as quickly.

GENERAL FIELD NOTES.

General field notes have been made regarding the native vegetation, beginning with the year 1915. Phenological dates are recorded for 27 different species of plants that are common on the prairie. These notes show that the prairie during the period from 1915 to 1921, inclusive, has turned green as early as April 15 and as late as May 20; it has started to show signs of "drying up" as early as June 15 and as late as August 15.

The points of main interest and importance in relation to the production of forage for grazing are (1) the time of starting spring growth and (2) the period of maximum growth. The problems of pasture management depend largely upon the time (1) of flowerstalk production, (2) fruiting, and (3) seed maturity.

The data in Table 10 are presented to show the periods of growth of the more important plant species. The dates in each case are the earliest and the latest that have been recorded.

It will be noted that there is considerable variation in the time the plants start their annual spring growth. This is largely determined by the season.

The field notes furnish a means of ready reference in regard to the periods of growth and development of the different plant species that can not be obtained as clearly in any other way.

TABLE 10.—*Periods of time when the most important plant species start their spring growth and mature their seed.*

Species.	Start of spring growth.	Period of seed maturity.
Bouteloua gracilis	Apr. 15 to May 15	August to Sept. 15.
Stipa comata	Apr. 1 to May 1	June 25 to July 10.
Koeleria cristata	Apr. 1 to Apr. 25	June 20 to June 30.
Carex filifolia	Apr. 1 to Apr. 20	May 20 to June 1.
Carex heliophila	....do	May 25 to June 10.
Artemisia frigida	Mar. 25 to May 1	Sept. 10 to Oct. 1.

OTHER STUDIES BEARING UPON THE EXPERIMENT.

MOWING EXPERIMENT.

This phase of the studies bearing upon the grazing experiment was started for two reasons: (1) To determine the quantity of hay annually produced and (2) to determine the effects upon total production of annual and biennial mowing. The mowing experiment was not begun until 1919, although plans had been completed for it previous to that time. Figure 11 shows the plan and arrangement of the units for mowing. The units in the center are mowed annually and those on either side in alternate years. They are 1 acre in size, and the hay from each is weighed separately. In 1919 the 9 acres were mowed and weighed. Some of the units had not been cut since 1915, while those on the east side were mowed in 1918. The yields from the different units are presented in Table 11. While there has been only one year, 1921, that the biennial units have been mowed as such, the yield is striking. The same relative difference is also true for the clipped quadrats which are cut annually and biennially and yielded at the rate of 799 and 1,664 pounds per acre, respectively. The old growth of 1920 made up about 35 per cent of the total weight. The increased yield, therefore, is not entirely the accumulated growth of the previous year, but is partly caused by the increased vigor and consequent greater growth of the vegetation of the current season.

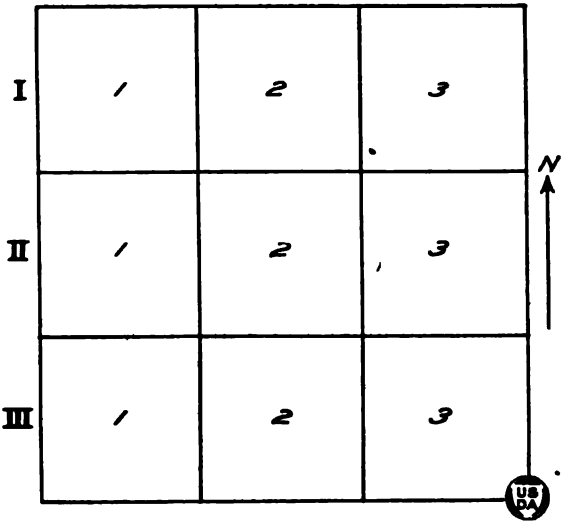

FIG. 11.—Diagram showing the plan of the mowing experiment (area, 9 acres): I, Mowed in odd years; II, mowed every year; III, mowed in even years.

The hay from the units mowed in alternate years was of poorer quality than that from those cut annually. This was because the

weeds in the biennial units were coarser and because of the accumulated growth of 1920, which made the hay "dusty." Each of these factors reduces the feeding value of the hay. There is also more waste in feeding the hay from the biennial units, but perhaps not enough to overcome the difference in yield.

TABLE 11.—*Yields of native hay for the years 1919 to 1921, inclusive.*

[Series I is mowed in odd years, Series II each year, and Series III in the even years.]

Year mowed.	Acre units.	Yield of hay per acre (pounds).			
		Series.			Average.
		I.	II.	III.	
1919	[1] 1	726	855	519	700
	[2] 2	560	492	607	583
	[3] 3	426	413	592	477
Average		570.7	586.7	602.7	586.7
1920	1	.....	287	210	.....
	2	.....	229	210	.....
	3	.....	199	242	.....
Average		.....	238.3	220.7	.....
1921	1	548	258	.....	.....
	2	628	330	.....	.....
	3	655	335	.....	.....
Average		610.3	307.7	.....	.....

[1] Not mowed since 1915. [2] Part mowed in 1916 and 1917. [3] Mowed in 1918.

The mowed units bear a direct relation to the grazing experiment, as they at once supply data upon which to base an estimate of the extent of the feed annually available for grazing. The units also bear a direct relation to the clipped quadrats. The quantity of feed the cattle obtain by grazing is between that of the yields of the mowed units and the clipped quadrats. The cattle get feed by grazing that is not recovered by a mowing machine, but they do not graze as closely as the vegetation is removed in the clipped quadrats.

Blue grama grass and the two species of Carex enter but slightly into the hay, as during most seasons they are too short to be cut with a mowing machine.

FIELD GERMINATION TESTS.

Field germination tests have been made with more than 30 species of native grasses. The seeds were collected during 1916 and 1917 and were planted in the grass nursery in the spring of 1918. Seeds of some of the more common species have been collected and planted since that time. In no case has any one of the highly important grazing grasses shown a high degree of germination. *Bouteloua gracilis* is very low in vitality and produced only two or three plants from several hundred seeds sown. The same is true for *Stipa comata*. However, another species of Stipa (*S. viridula*), which is not common on the prairie, has a germination equal to that of the ordinary field crops. *Koeleria cristata* also has shown a very low germination. Seasons more favorable to the growth and ma-

turity of the grasses may show an improvement in germination, but from all available data it appears that the seeds of many of the important grasses have a low degree of vitality. These grasses are able to maintain themselves under normal conditions by their strong vegetative growth and in favorable seasons by the production of a large number of seeds, a few of which will grow and become established.

SEEDING EXPERIMENTS IN NATIVE SOD.

A number of attempts have been made each year to establish some of the cultivated forage crops in the native sod without breaking it. Trials have been made with brome-grass, alfalfa, sweet clover, and the wheat-grasses both with and without disking the sod. These trials have furnished but slight encouragement for such a practice. The dry seasons may have prevented securing a stand, as practically every year some seedlings start growth but dry up before the end of the season. The native sod is already supporting all the vegetation possible, and unless this is destroyed by breaking there is but slight chance of anything else being able to compete with it.

SOIL MOISTURE.

Soil-moisture determinations have been made in each of the continuously grazed pastures every year since the experiment started in 1916. The soil samples have been taken around the quadrat area in each case.

The first foot of soil has been filled with water at the beginning of the season each year, but in all pastures has been reduced to the minimum before the end of the season every year since 1917.

The second foot of soil was filled with water at the beginning of the seasons of 1916 and 1917. It has not been completely filled since that time during any part of any season.

The moisture in the third foot has decreased from about 20 per cent in 1916 to 11 per cent in 1921 in all pastures. The same general reduction has held true for the fourth foot. The reduction of moisture in the fifth and sixth feet did not become pronounced until 1919. This was also true for wheat plats in the rotations at the station.

The soil-moisture data show very clearly that there has been a reduction of moisture in the sixth foot of all pastures except the 30-acre pasture. In this pasture there has been but little change in moisture content in the sixth foot since the middle of the season of 1919. This has no doubt been caused by the intense grazing. All of the plants except *Artemisia frigida* are eaten before they have a chance to use moisture to a depth of 6 feet. The available moisture at this depth has not been required by *A. frigida* because of the reduction of competition with other species for moisture above the sixth foot.

PALATABILITY OF THE VEGETATION.

The grasses annually produce from 45 to 55 per cent of the dry weight of all species. This fact is one of the highest significance, since it indicates an area of high grazing value for cattle.

In general, cattle and horses use a grass range to better advantage than sheep. Sheep relish tender green foliage and the grains of many grasses, but they eat

sparingly of coarse or dry grass foliage. Cattle consume a much larger proportion of the coarse grass forage. Horses, even more than cattle, prefer grass to weeds and browse.[26]

It is not only a matter of interest, but one of importance to know what a steer likes or dislikes while he is grazing native vegetation. It has often been said that "a steer will eat anything he is obliged to." This is literally true, but he always shows a marked preference for certain species of plants over others.[27] This preference may to a large extent determine the best system of grazing in order to make the maximum utilization of the vegetation and avoid overgrazing.

The palatability for cattle of the grass species is high. It is estimated that the grasses of this section of the Great Plains are 90 per cent palatable. This means that there are but few grasses that cattle will not eat readily and at any time without being forced to do so because of the shortage of forage.

The following grasses enter more or less into the feed of grazing animals and are listed in their order of palatability: *Bouteloua gracilis* (blue grama), *Andropogon furcatus* (big bluestem), *Stipa comata* (western needle grass), *Koeleria cristata* (prairie June-grass), *Bouteloua curtipendula* (tall grama), *Andropogon scoparius* (little bluestem), *Muhlenbergia cuspidata* (prairie rush-grass), *Calamovilfa longifolia* (big sand-grass), *Stipa spartea* (porcupine grass), and *Aristida longiseta* (wire-grass or triple awn-grass). Further discussion of most of the above grasses and their chemical composition may be found in other publications of the department.[28]

Blue grama is placed at the head of the list, because it is the one grass that cattle do not hesitate to graze at any time during the season after it has reached the grazing stage early in June. In the early season, while it is green and fresh, cattle eat it readily. In the autumn, after it has matured, the cattle will nose down through other species to obtain blue grama. This grass, which passes under the names of "grama" and "buffalo grass," has a better reputation for grazing in the Great Plains than any other single species of grass unless it is the true buffalo grass (*Bulbilis dactyloides*), with which it is often confused in the popular mind, which, however, occurs sparingly in this part of the Great Plains.[29]

Big bluestem is placed second in palatability because it is grazed with extreme relish by the cattle during the early part of the season. This grass is not an upland species, but thrives best along river bottoms; it occurs, however, in several small ravines in the pastures. This is the first grass that the cattle "clean up" early. They graze it close at once and will often pick over an area that has already been closely grazed while there is abundant feed in other parts of the pasture. This has been observed each year since the experiment started. However, in the fall when they have a chance to eat this grass on an area that has not been grazed that season, they will not graze it until other feed becomes scarce. There is a good reason for this seasonal choice. In the spring big bluestem is

[26] Jardine, James T., and Anderson, Mark. Range management on the National Forests. U. S. Dept. Agr. Bul. 790, 98 pp., 4 figs., 32 pls. 1919.

[27] Thornber, J. J. The grazing ranges of Arizona. Ariz. Agr. Exp. Sta. Bul. 65, 360 pp., 6 figs., 12 pls. 1910.

[28] Griffiths, David, George L. Bidwell, and Charles E. Goodrich. Native pasture grasses of the United States. U. S. Dept. Agr. Bul. 201, 52 pp., 9 pls. 1915.

[29] Sarvis, J. T. Composition and density of the native vegetation in the vicinity of the Northern Great Plains Field Station. *In* Jour. Agr. Research, v. 19, pp. 63–72, 2 figs., pls. 12–14. 1920.

tender, juicy, and sweet, and it also has a very pleasant odor, but by fall it has become harsh and woody and lost its sweetness and is then passed by for something better.

Western needle grass is eaten readily by cattle early in the season up to the time the needles form and become sharp. For a period of two to three weeks it is avoided by stock, but when the needles drop it is again taken well, even after it has become dried. This grass starts growth early in the spring, before most other grasses. It also grows late in the fall and produces some green feed after most of the other grasses have ceased growth for the season.

Prairie June-grass is one of the earliest grasses to start growth in the spring and is the earliest one to reach maturity. It furnishes luxuriant green feed during late May and early June which is readily eaten by the cattle. It soon dries up, however, and the foliage is almost entirely lost to cattle in areas that are not grazed early in the season.

Tall grama grass produces feed early in the season that is readily eaten by stock. It makes a much taller growth than the blue grama. In the early part of the season the foliage is tender and sweet, but later the stems become tough and woody.

Little bluestem seems to be more or less avoided by cattle. This is partly because the old stems are stiff and protect the young growth in the spring. On areas where this grass has been grazed down by cattle they do not hesitate about grazing the same area the next season while the growth is tender.

The other grasses are of minor value for grazing, from the standpoint of their palatability. They are all somewhat tough and are therefore avoided. Wire-grass (Aristida) is the last grass that the cattle will take when forced to graze a short range. Bunches of this grass are often found scattered over the pasture when everything else around them has been eaten. When the cattle start to eat the bunches of this grass it is a good indication that they are out of other feed. The awns of this grass are very sharp, and they do not readily drop, as in the case of species of Stipa.

The two species of Carex are high in palatability for cattle early in the season and are estimated at 100 per cent palatable until late June. As the summer advances their palatability decreases to practically nothing for *Carex filifolia* (nigger wool) by the close of the season. This species becomes dry and tough with age. *C. heliophila* (western prairie sedge)[30] remains palatable longer and is not greatly avoided by the cattle at the close of the season.

The palatability for cattle of the other plants is low; it is estimated at not more than 30 to 40 per cent. It is true that the cattle eat most of these plants when other feed is scarce, but of their own choice they eat only a small percentage. The plant that they avoid most of all is *Artemisia frigida*. They will not eat this at any time until they are forced to do so. As already mentioned, in the 30-acre pasture, where this plant has become coarser than in the other pastures, the cattle reject it until the last and lose weight while a considerable portion of it is still untouched. None of the other species are particularly avoided. The low palatability of these

[30] This name has been applied locally to this species, as the plant is very common, and it is often desirable to refer to it under a popular name.

plants generally reduces the value of the total vegetation of this region. It is estimated that the palatability for cattle of the vegetation as a whole is approximately 75 per cent, but that 95 per cent of it will be eaten when cattle are forced to graze a short range.

CAUSES OF THE DETERIORATION OF NATIVE PASTURES BY GRAZING WITH CATTLE.

The main causes of the deterioration of native pastures when grazed by cattle are (1) too early grazing in the spring, (2) continuous grazing, and (3) overgrazing.

While it is the universal practice to turn the cattle into the pasture as soon as the snow is off the ground in the spring, this fact can not obviate the injury to the vegetation. This injury is caused by the trampling of the cattle in the wet soil and by their picking off the young vegetation as soon as it starts growth. Grazing in the northern Great Plains should not begin before May 1 to May 15. By that time the vegetation has usually made enough growth so that it can keep ahead of the grazing. The grazing experiment at Mandan has never been started before May 15. There are conditions under which cattle may be turned on the native pastures early in the spring without serious results except the damage done by trampling. These conditions are found in pastures that are annually undergrazed and therefore have sufficient old growth to maintain the cattle for a short period.

While continuous grazing at the proper rate may not directly injure the vegetation as a whole, some species are likely to be weakened because of overgrazing, while others may become so coarse that they are avoided because of undergrazing. Cattle will eat certain species in preference to others each season, which will result in severe injury to the preferred species. This point is well illustrated in the case of big bluestem in the 100-acre pasture. A small area of this grass occurs in a depression. Each spring the cattle have grazed this grass and kept it short, until at the present time the area has become infested with weeds and its grazing value reduced.

Overgrazing is brought about by trying to feed too many cattle upon too few acres. This is the most common cause of native-pasture deterioration. If continuous overgrazing is practiced long enough it will eventually mean the abandonment of the land for pasture purposes. The cumulative effect of overgrazing is brought about by the continual removal of the vegetation year after year without affording it an opportunity to produce a crop normally. This condition will sooner or later mean the death of most of the valuable grazing plants.

The system of deferred and rotation grazing is designed to reduce to a minimum the causes of deterioration of native pastures. This is effected by allowing each division of the pasture to bear its burden of early-spring grazing equally with other divisions and also allows each division to share equally the benefits of normal growth and grazing after the maturity of the vegetation.

The following citations have a direct bearing upon the above points:

The permanent welfare of the livestock business itself demands that the grazing seasons should not begin too early, because the maintenance of the maximum permanent carrying capacity of the range is identical with the permanent welfare of the communities or individuals depending upon the range.

Premature grazing was undoubtedly one of the foremost causes of the deterioration of range lands prior to regulated grazing; and the fixing of grazing periods on the lands within the National Forests has had as much to do with range improvement as reductions in number of stock, if not more.[21]

(1) Removal of the herbage year after year during the early part of the growing season weakens the plants, delays the resumption of growth, advances the time of maturity, and decreases the seed production and the fertility of the seed.

(2) Under the practice of yearlong or seasonlong grazing both the growth of the plants and seed production are seriously interfered with. A range so used when stocked to its full capacity finally becomes denuded.

(3) Grazing after seed maturity in no way interferes with flower-stalk production. As much fertile seed is produced as where the vegetation is protected from grazing during the whole of the year.

(4) Deferred grazing [grazing after seed maturity] insures the planting of the seed crop and the permanent establishment of seedling plants without sacrificing the season's forage or establishing a fire hazard.

(5) Deferred grazing can be applied wherever the vegetation remains palatable after seed maturity and produces a seed crop, provided ample water facilities for stock exist or may be developed.

(6) Yearlong protection [against grazing] of the range favors plant growth and seed production but does not insure the planting of the seed. Moreover, it is impracticable, because of the entire loss of the forage crop and the fire danger resulting from the accumulation of inflammable material.[22]

GRAZING CAPACITY BASED UPON THE NATIVE VEGETATION.[23]

The investigations in connection with this experiment are by no means completed. It is recognized that further experimentation may intensify or modify the results already obtained. The results so far secured, however, have an important bearing upon the value of different systems and intensities of grazing and the effects upon the native vegetation. It is not expected that the continuance of the severe grazing in the smaller pastures will afford them an opportunity to recuperate enough to regain their maximum grazing capacity even under the most favorable seasonal conditions.

It might appear that the grazing capacity of the vegetation, as measured by the effects of different intensities of grazing, is antagonistic to the most economical gains of the cattle and to efficient range management. However true this might appear from the earlier results of the grazing experiment, the two must eventually coincide, since the cattle are entirely dependent upon the native vegetation for their food supply while grazing. Any system or intensity of grazing that will allow the plants to continue their maximum seasonal production will be reflected in the gains of the cattle. The most efficient system of grazing may or may not be the one that produces the most immediate profit, but it will produce the most profit

[21] Jardine, James T., and Anderson, Mark. Range management on the national forests. U. S. Dept. Agr. Bul. 790, 98 pp., 4 figs., 32 pls. 1919.

[22] Sampson, Arthur W. Natural revegetation of range lands based upon growth requirements and life history of the vegetation. *In* Jour. Agr. Research, v. 3, pp. 93–148, 6 figs., pls. 12–23. 1914.

[23] The term "grazing capacity" has been used in this publication in preference to "carrying capacity," as it more nearly expresses the manner of forage utilization. This term has also been applied in other publications. See Jardine, James T., and Anderson, Mark. Range management on the national forests, U. S. Dept. Agr. Bul. 790, 98 pp., 4 figs., 32 pls., 1919; and Smith, Jared G., Experiments in range improvement, U. S. Dept. Agr., Div. Agros. Circ. 8, 5 pp., 1 fig., 1898.

per cent more cattle can be grazed on the same area. This will in a short time more than pay for the extra cost of fences. This system of grazing could be readily applied on many farms or ranches. It often happens that the land for pastures is divided by roads, so that it is necessary to operate independent pastures. When such a condition exists the system of deferred and rotation grazing can be put in operation at once without additional cost.

SALIENT POINTS REVEALED BY THE GRAZING EXPERIMENT.

Of more than 250 species of plants at the Northern Great Plains Field Station, less than a dozen play a dominant rôle in grazing.

Bouteloua gracilis (blue grama grass) is the species least injured by heavy grazing and apparently is benefited by moderate to close grazing.

Stipa comata (western needle grass) is the species most injured by heavy grazing.

Artemisia frigida (pasture sage) is the best indicator of overgrazing, because cattle do not like it, and it is able to take advantage of the weakened condition of other plants and increase in number and size per unit area.

The range vegetation makes 75 per cent of its growth during May and June.

The total gains that can be made on native pastures in this area of the Great Plains have never been fully realized by stockmen or those interested in grazing problems.

In a grazing experiment it is equally important to know what is happening to the cattle and to the vegetation.

Cattle make their largest gains during the early season on green grass and not in the fall on mature grass. This is true as long as the quantity of feed early in the season is not a limiting factor.

Cattle grazing on a short range may appear to be doing well when, in fact, they are no more than maintaining their weight.

Grazing longer than four months has not increased the gains per head, but has resulted in a better "finish."

Under a system of continuous grazing it requires 7 acres to graze one 2-year-old steer for five months.

Between 4 and 5 acres will graze a 2-year-old steer for five months under a system of deferred and rotation grazing.

The highest gain per head of cattle is not correlated with the highest gain per acre.

The lowest gain per head made on the lowest acreage is correlated with the highest individual gain per acre, provided the cattle are not forced to remain on a short pasture for too long a period.

The measure of efficiency of a pasture or system of grazing is not determined by one factor but by several of equal importance.

CONCLUSIONS AND SUMMARY.

The cooperative grazing experiment reported upon in this bulletin was established at the Northern Great Plains Field Station, near Mandan, N. Dak., in 1915. Its objects were to determine the grazing capacity of the native range and the effects of different systems and intensities of grazing upon the native vegetation.

The experiment is conducted with four pastures under a system of continuous grazing. These pastures vary in size from 100 to 30 acres. A pasture of 70 acres conducted under a system of deferred and rotation grazing was added in 1918.

The land used for the experiment is not materially different than other vast areas in western North Dakota. This land, however, is better than would ordinarily be used for grazing. It is well adapted for experimental purposes because of its uniformity.

Early seasonal precipitation exerts a greater influence upon the production of native forage than upon other crops.

The deferred and rotation system of grazing is designed to allow different divisions of the pasture to mature a crop normally before it is grazed. Under this arrangement a greater utilization of the vegetation is obtained with less injury to it than in any other pasture, and with the greatest total gain.

The grazing season for this experiment is five months during the summer. Winter grazing is not taken into consideration and is not recommended for this section except under very unusual conditions.

The cattle used in the experiment are 2-year-old grade steers. They are weighed individually at 30-day intervals throughout the season.

The cattle have made average gains per head ranging from 294 pounds in the 70-acre pasture to 180 pounds in the 30-acre pasture. A high gain per head does not produce the largest gain per acre. A gain per head higher than the small pastures but lower than the large pastures is produced on the deferred and rotation pasture. The total gain per acre in the rotation pasture has been higher than in any of the others since the number of cattle has been increased.

The quantity of the foliage cover annually removed by grazing varies on the average from 51 per cent in the 100-acre pasture to 98 per cent in the 30-acre pasture. In order to avoid injury to the vegetation under a system of continuous grazing, from 15 to 25 per cent of the foliage cover must remain on the pasture at the close of the grazing season. A greater utilization of it may be made under the system of deferred and rotation grazing.

The most efficient system of grazing is one that will insure sufficient forage during the entire season to produce the greatest total gain in weight with the least number of cattle on the minimum unit of land without permanent injury to the native vegetation. The requirements of this measure of grazing efficiency are most nearly fulfilled by the deferred and rotation system of grazing.

Botanical studies in connection with the grazing experiment are necessary in order to determine the effect of different systems and intensities of grazing upon the native vegetation.

The vegetation has a total basal cover of approximately 60 per cent. Of the basal cover 20 per cent is made up of *Bouteloua gracilis*, 10 per cent of *Stipa comata*, and 30 per cent of other vegetation.

The dominant species are *Bouteloua gracilis*, *Stipa comata*, *Carex filifolia*, and *C. heliophila*.

As the vegetation is the "climax" type, having the highest development, the grazing should be so adjusted as to maintain it without deterioration.

The mapped quadrats used in these experiments are of value in securing a permanent record of the composition of the

native vegetation. They also indicate the effects of grazing upon species that grow in mats or small bunches. From these maps it is clear that the quantity of *Stipa comata* has been reduced by the overgrazing in the 30-acre pasture.

The list quadrats used in these experiments are of great value in keeping a record of the number of plants of different species. These quadrats show that *Artemisia frigida* has increased in extent under the heavy grazing in the 30-acre pasture. The vigor of the individual plants of this species has been favored by the reduction of the competition of other species in the small pasture.

The clipped quadrats used in the experiment were designed to facilitate the study of the effects of frequent and infrequent removal of the vegetation upon its subsequent growth and also to determine the period of greatest growth. In the frequently clipped quadrats *Stipa comata* has disappeared, other species have been weakened, and the total production has been reduced. *Bouteloua gracilis* is the one species that appears to respond to frequent clippings better than any other species. The greatest growth of the vegetation occurs early in the season at the time the cattle make their greatest gains.

Photographs of the plants growing in the different pastures have been taken from the same points each year. These form permanent authentic records that can not be obtained in any other way.

Areas known as "isolation transects" were set aside in the 100-acre and 30-acre pastures and in one division of the rotation pasture. Units are annually closed to grazing on one side of the transect and opened to grazing on the other, while the central units are never grazed. The units that are annually closed to grazing in the 30-acre pasture contain about five times as many plants of *Artemisia frigida* as those that are never grazed. The plants of this species are also more vigorous in the units closed in 1920 and 1921 than in those closed previous to 1920.

General field notes are kept each year upon 27 different species of plants that are common on the prairie. These notes show that the prairie has turned green in the spring as early as April 15 and as late as May 20, while it has started to "dry up" as early as June 15.

A mowing experiment was undertaken to determine the effects of the annual and biennial removal of the vegetation upon the total production. The yields also furnish data from which the quantity of forage available for grazing may be determined.

Field germination tests show that the seeds of many of the most valuable range grasses are low in vitality.

Each year a number of trials have been made to grow cultivated forage plants sown in the native sod without breaking. The results show that it is almost impossible to get the plants to grow in a vegetation of such density.

Soil-moisture determinations show that the first foot of soil in all pastures is well filled with water at the beginning of each season. It was not until 1919 that the moisture of the sixth foot of soil was greatly reduced. The sixth foot of soil in the 30-acre pasture has not been reduced to the same degree as in the other pastures.

The grasses of this region make up about 50 per cent of the dry weight of all species of plants. It is estimated that 90 per cent of them are palatable and therefore afford excellent grazing for cattle.

Bouteloua gracilis and *Andropogon furcatus* are the most palatable grasses, while *Artemisia frigida* is the least palatable of all species of plants. Cattle do not like it and will not eat it unless forced to do so because of the shortage of other feed.

Native pastures deteriorate when grazed because of (1) too early grazing in the spring, (2) continuous grazing, and (3) overgrazing. All of these factors can be controlled.

The grazing capacity of the native vegetation of the area included in these experiments is shown by the results in the several pastures. The 100-acre pasture, grazed at the rate of one steer to 10 acres, is larger than is necessary to produce the maximum gains per head. This pasture is undergrazed. The 70-acre pasture, grazed at the rate of one steer to 7 acres, provides approximately the area of land required to produce the maximum gains per head under a system of continuous grazing. The 50-acre pasture, grazed at the rate of one steer to 5 acres, is not large enough to allow the cattle to make maximum gains per head. This pasture is overgrazed. The 30-acre pasture, grazed at the rate of one steer to 3 acres, is not large enough to carry the cattle for five months. This pasture is severely overgrazed. Under a system of deferred and rotation grazing the number of acres required per head is reduced to between 4 and 5. This acreage will provide enough feed to allow the cattle to make gains per head intermediate between those made in the 50-acre pasture and those made in the 70-acre and 100-acre pastures. This system allows the maximum utilization of the vegetation without the injury to it accompanying overgrazing.

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FOREST TYPES IN THE CENTRAL ROCKY MOUNTAINS AS AFFECTED BY CLIMATE AND SOIL

By

CARLOS G. BATES, Silviculturist

Fremont Forest Experiment Station, Forest Service

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INTRODUCTION.

In "Physiological Requirements of Rocky Mountain Trees," (*6*) [1] by the writer, published in the Journal of Agricultural Research (Apr. 14, 1923), the relative physiological requirements of the species composing the various forest types of the central Rocky Mountains have been discussed. The present work on climatic and soil conditions affecting the same forest types supplements that discussion. The two papers are, indeed, so closely related that the one is indispensable to the understanding of the other.

In the earlier paper the results of a number of laboratory studies were presented, in the hope that such comparisons, made under controlled conditions equally affecting all of the species involved, might permit judgment of the relative physiological requirements, and thereby make it possible more definitely to decide what conditions of the environment are really important in controlling distribution and what are merely variable concomitants of these controlling conditions. If the ensuing discussion presented from the standpoint of field observations does no more than reconcile the two

[1] Parenthetical figures (*italic*) placed in the text refer to corresponding numbers under "Literature cited" on page 152 of this bulletin.

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points of view and make clear what conditions of environment respond directly to physiological requirements and thus most vitally affect the composition of the forest, and in what terms these conditions must be measured and expressed, it is felt that an advance will have been made. But it is believed that a further progress has been made. In these two approaches to the subject the understanding of the relative qualities of the forest trees considered may become clarified for the reader, and thus assist foresters in reaching a proper understanding of the technical problems which are met almost daily. This belief is held notwithstanding the fact that the methods in ecological study of the environment are in some respects very crude and in these respects still afford opportunity for much intensive and fruitful work.

A brief review of the physiological work and of the conclusions which have already been presented is here given.

The historic concept of a difference between tree species as to "shade tolerance" or photosynthetic capacity has been borne out by observations on the growth rate during growing seasons and the sap densities at the end of these seasons, in which the several species were subjected to identical conditions. The six species considered seem to be photosynthetically effective in the following decreasing order: Engelmann spruce, Douglas fir, lodgepole pine, bristlecone pine, yellow pine, and limber pine.

As a direct result of greater photosynthetic activity, the water use per unit of growth is reduced; or, in other words, in relative "water requirements" the most "tolerant" or effective species take the lowest positions.

This also affects the absolute requirements, as expressed by transpiration per unit of leaf area or exposure, indirectly, through the relative evaporating rates of solutions of different densities, so that in a general way the most active species are absolutely the smallest users of water. It also appears in this connection that certain species may be much better adapted than others to resist transpiration on account of the thickening of the epidermis and the reduction of the stomata. This places them in a lower category with respect to the absolute transpiration rate, but does not appreciably affect their water requirements, because such economies can be effected only through means which exclude carbon dioxide or light from the functioning cells. Thus, Engelmann spruce, Douglas fir, and yellow pine appear in increasing order as absolute water users; but limber pine, bristlecone pine, and, to a lesser extent, lodgepole pine, take lower positions than would be expected, all being "weedy" trees which sacrifice growth rate for protection against great water losses.

In view of the behavior of weaker and denser solutions, it is conceived that the species which are most effective photosynthetically may be satisfied with the coolest environments, because, with their relatively dense cell saps a smaller proporation of the energy of the absorbed sunlight is used in the process of evaporation. In other words, a dense solution is not so rapidly cooled by its own evaporation as a lighter solution. Hence the possessor of the dense solution may more readily maintain leaf temperatures which will be conducive to effective photosynthesis. That the temperature of the leaf is important in this process can hardly be questioned. Thus the relative light requirements and heat requirements of the several species are seen to be identical. On the basis of light requirements the species would be zonated in the order already given, with spruce occupying the situations of lowest air temperatures.

It is also conceived that, as the most effective species is least readily cooled by the evaporation of its cell sap, it may not only require less heat for effective growth, but may most readily become superheated to the point at which direct protoplasmic injury results. For this reason no species may become established in a temperature zone or in an exposed site whose temperatures exceed a certain maximum. It must, however, be admitted that the direct evidence on this point is extremely meager. It is also apparent that the maximum temperatures encountered in nature, namely, those at the surface of insolated soils, are so intimately connected with the dryness of that layer and with the water supply and transpirational losses of young seedlings that evidence of direct heat injury, apart from injury through water loss, may be very difficult to obtain.

At this stage it is not unimportant whether the high temperatures of the surface soil react directly or indirectly, but it is of greater importance to recognize that the combined effects may be the most common cause of the death of forest-tree seedlings in the region under consideration. The present evidence is that the action is most commonly indirect; that spruce and lodgepole pine seedlings are most sensitive to excessive heat and drying, because their poorly developed roots and thread-like stems do not permit them to push the necessary supplies of water past the superheated section of the stem; that Douglas fir and yellow pine are relatively resistant, because they are much stronger both as to length of root and size of stem.

It would seem that the species which creates carbohydrates most readily, maintaining the sap of greatest density and osmotic pressure, would, by reason of the last-named quality, extract water from the soil to the lowest point, and there is no reason to believe that this is not the case. Even in carefully controlled pan tests, however, and more markedly in the field, drought resistance is much more than extracting the water from the soil particles with which the roots may be in contact. It is the ability to reach with the roots the supply of water that very largely determines which seedlings will last the longest. Thus although Engelmann spruce seedlings do resist drought remarkably well when the losses by transpiration are at a very low rate and when slow capillary action may assist in bringing water to the roots, yet ordinarily they succumb before Douglas fir or yellow pine seedlings, because the latter at the outset develop roots nearly twice as long. On the contrary, spruce trees of greater age, having developed a great many root branches, evidently have at their command a larger proportion of the water supply of a given soil space than either yellow pine or fir, whose roots are then coarse and few in number. Both because lodgepole pine develops a root as slowly as spruce, and because it apparently exerts a relatively low osmotic pressure, its seedlings stand out prominently as the least drought-resistant of those considered.

As a result of the various investigations upon the relative physiological functioning of the species named, Engelmann spruce (*Picea engelmanni*) and Douglas fir (*Pseudotsuga taxifolia*) may be considered to be the most highly developed plant organisms, in the sense of effecting most readily the processes on which growth is dependent; and at the other extreme are found western yellow pine (*Pinus ponderosa*) and limber pine (*P. flexilis*). Although further investigation may tend to alter the relative positions of the four pines, it is believed that acceptance of the order first given above will not be seriously misleading.

But apart from this physiological development, which is considered most fundamental, there are two lines of adaptation which evidently affect distribution. In the bristlecone (*Pinus aristata*) and limber pines, both of which are "weedy" or below the stature of true forest trees, and perhaps more facultative in adapting themselves to site, the stomata are greatly restricted in size. This inevitably reduces growth rate by making carbon dioxide less available. These trees are certainly resistant to the evaporation which might result from strong wind, but it is not believed that they are drought-resistant in the sense of exercising a strong osmotic control over their water supplies. This distinction is important, for, although the property of being resistant to evaporation makes them valuable on wind-exposed sites, it does not equip them for enduring the actual drought of the soil, which results, for example, from competition between trees.

On the other hand, in the early and vigorous root development of yellow pine and Douglas fir, as contrasted with lodgepole pine (*Pinus contorta*) and spruce, there is an effort on the part of the former to adapt themselves to the meager moisture supplies which usually obtain in the localities where these species find their proper heat conditions. It is believed that the heat conditions are fundamentally controlling,

and that the moisture conditions have been met by this adaptation as the need arose.

As between spruce and lodgepole pine there is plainly a distinction. The former is evidently under no stress to root vigorously, for under the temperature conditions to which it is adapted exhaustion of the surface moisture is a very slow process. Furthermore, according to the present interpretation, the species is capable of coping with a considerable degree of drought. It seems almost certain that lodgepole thrives best with relatively high temperatures, yet the root development is adapted only to existence in perpetually moist sites. The sluggish germination of lodgepole pine seeds, except when exposed to wide temperature ranges, suggests adaptation to open, exposed situations without other cover. From this and other bits of evidence it may be concluded either that lodgepole pine is a recent migrant to the central Rocky Mountains and is poorly adapted to a region of great atmospheric dryness, or is capable of developing only in the early stage of a succession, when competition for moisture is lacking.

With these facts and theories as a working hypothesis, it is now intended to examine the environmental conditions for evidence as to the factors which must be controlling in the formation of each forest type.

THE METHOD OF STUDY.

The primary data to be presented in this bulletin are records of climatic and soil conditions in different forest types. The main object of such a presentation must be to show that differences in climatic and soil conditions between the forest types either do or do not exist in sufficient degree to account for the varying phenomena of occurrences and growth.

As the special data collected by the Forest Service do not cover periods long enough to establish the "normal" conditions of any of the forest types (and by this is meant the average conditions for a period of at least 20 years), and since even the average conditions for a period of 10 years may vary considerably from "normals," it is necessary to assume that important differences between forest types are fairly constant, and will be brought to light by the consideration of short-period records. Such bases can not be fraught with any serious dangers, moreover, when, as in this case, the forest types to be compared are in the same general locality, that is, in the path of the same air currents and storm centers. Any considerable separation of the stations, however, especially in a rugged mountainous region, is likely to introduce temporary variations in certain conditions which are not "normal," and particularly in those conditions which are most directly influenced by the path of storm centers. Thus at the time of this writing it appears that the storm centers have for some time been passing considerably to the north of the Pikes Peak region, giving that locality unusual westerly winds and leaving it without its usual amount of moisture. Consequently as early as the end of May an unprecedented shortage of water exists, while scarcely 100 miles to the north unusually large accumulations of snow are reported.

Again, the moisture factor is most variably influenced by the restricted character of many of the summer showers; especially are

FIG. 1.—GENERAL VIEW OF SURROUNDINGS OF CONTROL STATION (F-1) MIDWAY BETWEEN THE TWO HOUSES.

Note lack of tree growth on crest of the ridge. January 5, 1911.

FIG. 2.—STATION F-3. ON THE RIGHT IS THE SOIL WELL, AND ON THE LEFT THE TOWER USED FROM 1910 TO 1912. GROUND CONDITIONS ARE RECORDED BEHIND THE CLUMP OF SAPLINGS IN THE CENTER.

In the foreground is a small reservoir holding the water of a spring which appears in the gulch bottom. July 7, 1918.

FIG. 1.—STATION F-2, SHOWING THE FOREGROUND SOIL WELL, THERMOMETER PIPES, AND EVAPORIMETER, AND IN THE BACKGROUND, TOWER ON WHICH OBSERVATIONS WERE MADE FROM 1910 TO 1912. JULY 7, 1918.

FIG. 2.—STATION F-6, LOOKING ACROSS THE SLOPE.

Note the sparseness of the vegetation in the foreground where it has not been disturbed. July 7, 1918.

the heaviest downpours in a given locality likely to affect only very small areas. Temperatures are generally not so directly affected by local conditions. Thus the month of December, 1917, was an unusually warm month not only at the Fremont Forest Experiment Station, but over most of the western part of the United States. January, 1918, likewise, was generally cold to an unusual degree. It seems safe, therefore, to compare the records of any two near-by stations for short periods, whatever the factors under consideration, and an increasing period will be demanded as the distance between stations increases.

Fortunately the dozen or more stations located in the vicinity of Fremont all come under the same general influences. This is true of the entire area from the plains to the summit of Pikes Peak, with the exception that summer rains frequently fall in one part of the area and not in others. Winter snows may also be so localized, but usually in conformity with altitudinal zones. It is true that two stations not 100 yards apart may on a given day have temperatures varying by 2° F. in one direction, and on the next day varying in the opposite direction. Such variations from a consistent relation are, however, always small, and there is every reason to believe that the means of a single month usually express essentially the normal temperature relation between two stations for that month of any year.

Therefore the method of presenting results in this bulletin is to compare each condition at any outlying station, for whatever period observations may have been taken, with the corresponding condition recorded during the same period at the so-called "control station." The latter is merely a single point, near the headquarters of the Fremont Forest Experiment Station, at which all of the factors to be considered have been measured almost continuously from 1910 to 1921, or later, with the important exception of the evaporation factor for which satisfactory measurements were not obtained until 1916.

In the study of air temperatures, several attempts have been made to cover the somewhat distinct sets of conditions which may exist at any station—that is, to measure both the very local air temperatures near the ground and those well above the ground, which may represent the mean for the locality, obtained by the mixing of the warmer and cooler strata of air. On a breezy day, of course, this mixing is constant and effective and even brings together the warm air near the earth and the much cooler air of high strata in the atmosphere. On quiet days such mixing may be very incomplete, so that even at 20 feet above the ground temperature records may reflect local rather than general conditions. Sudden changes of temperature are then likely to be recorded when a stronger movement of air begins.

The temperature of the air close to the ground is a condition in which foresters are greatly interested because of its relation to seedlings and young growth. A number of observations have been made at an elevation of 1 foot from the ground surface, and these will hereafter be spoken of as "ground temperatures" in contrast with temperatures in the soil, on the one hand, and the temperature of mixed air at higher levels, on the other. At the "ground" elevation the rate of air movement is low, and, unless brisk breezes are blowing, is such as to permit the air to attain almost the temperature of the ground and of the vegetation with which it comes in contact. An elevation of 1 foot was adopted for ground temperatures, because it

was the lowest elevation at which maximum and minimum thermometers could be conveniently operated without seriously disturbing the snow blanket, and because it was thought adequate to represent purely local conditions of absorption and radiation. An elevation of 4½ to 6 feet, which is very convenient, may represent a good degree of air mixing without nullifying local character, except to modify daily extremes. With greater elevations, which have been used in a few instances to measure the conditions affecting the crowns of trees, it will be seen that the local character of the temperatures partly disappears.

In securing temperature records at these elevations the ordinary method of exposing thermometers is not satisfactory where wind is very light. Unless there is considerable wind to cause constant change of air within a standard thermometer shelter, the temperatures recorded are certain to reflect the heat absorption of the walls of the shelter itself during the day, and at night the degree of heat retention by the same walls, rather than the absorption and radiation of natural objects. Although, because of the free air movement, this influence is not very potent at considerable elevations above the ground, special precautions must be taken in exposing thermometers for ground temperatures. Direct insolation of the thermometers must of course be prevented. At the risk, however, of some reflected radiation striking the instruments, it has been found best to attach them to the north faces of boards and to protect them from the sun above and on the east and west, leaving them open to air currents on the north. There is nothing below them to interfere with ground-and-air cooling at night. Where standard shelters have been used on the ground, their doors have been constantly open to the north except for short periods, and usually the floors have been partly open. Although by no means all obstacles to proper temperature recording have in this manner been removed, it is believed that the records presented contain only occasional errors due to improper exposure.

Records of evaporation have been obtained with a variety of instruments and methods, omitting evaporation from free-water surfaces, but while an attempt has been made to compare the results obtained by different methods, it must be recognized as a general principle that such comparisons are of little value. Inasmuch as the rate of evaporation at any time is dependent not only upon the heat supplied by the sun and the air in contact with the evaporating surface, but also upon the rate of diffusion of the vapor as influenced by wind movement and atmospheric humidity, it is irrefragable that two different evaporating instruments or surfaces, with constant variations in each of these four contributing factors, can not maintain constant relative evaporating rates (*5*). Furthermore, it is hopeless to expect that the response of any instrument or evaporating surface will bear a constant relation to the response of any given plant, which must be differently affected by each of the four factors. The problem is made even more intricate by the variation in the capacity of different plants for sunlight absorption and for transpiration. For these reasons, the comparisons of types are based almost wholly on records of Type 4 evaporimeters, although some of these records were not obtained until the early part of 1921.

Methods of soil study are so far from being standardized, and the methods used by agricultural investigators are in some respects so

inapplicable to mountain soils, that considerable ingenuity has been required to develop suitable procedure for this study. The aim has been to obtain an accurate measure of soil temperature on the one hand and on the other to determine the moisture content of the soil throughout the growing season. At the same time measurements have been made of those more or less stable soil qualities which have an influence upon the availability of soil moisture. After considerable observation and experiment the conclusion has been reached that soil-moisture data can be directly valuable in such a study as this only if they are reducible to terms of exterior osmotic pressure, which is opposed to the osmotic pressure in the plant itself. Although soil-moisture quantities have not been measured in exactly these terms, in the data certain guides are found by which the relative osmotic pressures may be approximated. There remains, however, a great need for further refinement of the data and for new methods especially applicable to the surface of the soil.

The special conditions affecting the value of the soil moisture and temperature data will be described under these respective captions just before the presentation of the results.

DESCRIPTION OF THE LOCALITIES STUDIED.

For the purpose of compilation the stations have been arranged in alphabetical and numerical series, rather than according to the forest types which they represent. The letter represents the initial of the geographic name by which the station is likely to be known, and the number indicates simply the serial order under each letter in this particular study. As the reader is not likely to hold these descriptions in mind and may wish to refer to them frequently, the indexing idea will prevail in their arrangement, except that the control station at Fremont will be first described.

F-1: Control station.—Elevation, 8,836 feet; aspect, S. 15° W.; slope, 21 per cent. Whether this station represents any forest type or will for ages remain a grassy park is very uncertain. It is situated practically on the crest of a narrow east-west ridge, lying only a few feet above stream channels on either side. The ridge represents granite in situ, however, rather than stream deposit. At the exact spot where the instruments are located there were no tree specimens, but a very compact sod. Within 30 feet, on the southerly slope, aspen, limber pine, and yellow pine seedlings were found, the aspen particularly being of very poor development, the nearest trees not over 10 feet high. On the northerly slopes of the same ridge yellow pine, limber pine, and Engelmann spruce form a poorly defined stand. Irregularities in conformation also give room for birch and aspen on this slope.

In the light of both topographic and vegetational evidence, the exact spot at which the station is located must be considered to represent conditions most conducive to a growth of yellow pine or perhaps limber pine. This classification, however, is not so important, since the station was designed primarily to secure data for the general atmospheric conditions of the Douglas fir zone in which it lies; and for the study of either atmospheric conditions or soil conditions one common point of comparison is perhaps as good as another. The records of this station are used in all comparisons of type conditions.

To make the records as free as possible from purely local influences, all atmospheric conditions have been observed on a tower so constructed that the thermometers, anemometers, evaporimeters, and other apparatus could be placed about 20 feet above the ground. (See Pl. I, fig. 1.) At this height no artificial influence acts upon any of the instruments, and even the nearest trees are too distant to have any appreciable effect upon wind movement or direction, although both movement and direction are strongly influenced by the configuration of the larger valley in which this small ridge lies. In 1917 a house was erected about 30 feet to the northwest of the tower, with the roof comb slightly higher than the instruments on the tower; but no effect from this structure has been noted in any of the records, and it is not thought that an appreciable effect can be produced by it, either upon temperature or wind movement.

In addition to the records obtained on this tower, it was thought desirable, in 1916, to measure air temperatures near the ground, as was being done at many of the outlying stations, in order that knowledge might be had as to the influence of elevation on temperatures. These ground temperatures go under the station number 1–G to distinguish them from the records designated 1–A. The equipment of this station, where most of the observations have been continued to date, has been as follows:

Tower (F–1A):
Maximum and minimum thermometers, in standard shelter. Standardized U. S. Weather Bureau instruments used, January, 1910, to April, 1920.
Air thermograph, March, 1910, to April, 1920.
Anemometer, standard, with register, February, 1910, to date.
Wind vane, with register, February, 1910, to date.
Sunshine recorder, electric themometric, with register, February, 1910, to date.
Psychrometer, January 21, 1910, to April, 1920.
Evaporimeter, inner-cell, Type 2, March 22, 1916, to January 1, 1917; inner-cell, Type 4, January 1, 1917, to date.
Ground (F–1G):
1-foot soil thermometer, in iron pipe, February 10, 1910, to September, 1918.
2-foot soil thermometer, in iron pipe, February 10, 1910, to June 30, 1914.
4-foot soil thermometer, in iron pipe, July 1, 1914, to date.
1-foot soil thermometer, in wooden tube, February 20, 1918, to June 10, 1920.
Maximum and minimum thermometers, on shielded board, April 1, 1916, to February 20, 1918.
Maximum and minimum thermometers, in standard shelter, February 20, 1918, to September, 1918.
Air thermograph, in standard shelter, February 20, 1918, to September, 1918.
8 and 12 inch rain gages, with register, January, 1910, to date.
Soil well in operation from June 29, 1914, to 1918. Determinations of moisture during growing season at depths of 1, 2, and 3 feet, and for 1917 at surface.

No records whatever for any of the above-described equipment were obtained during the periods from January 21 to March 20, 1914; from December 11, 1914, to February 28, 1915; and from September 21, 1918, to May 1, 1919. For some conditions, the record obtained up to 1918 seems adequate for establishing practically normal values; for others, the two succeeding years introduce very different values, and their records are therefore used.

C–1: Colorado Springs plains.—Elevation, 6,098 feet. On flat plains about 100 feet higher than the valley of Monument Creek, immediately adjacent on the west. The observations here were taken on the roof of one of the buildings on the campus of Colorado College, possibly 50 feet above the ground. The building is practically on the break between the flat plains which lie to the east and the valley of

FIG. 1.—STATION F-4, LOOKING NORTHWARD, SHOWING THE CHARACTER OF THE WESTERN YELLOW PINE TIMBER WHICH FORMS THE MAIN CANOPY. JULY 7, 1918.

FIG. 2.—STATION F-5, SHOWING THE CLUMP OF SPRUCE TREES WHICH SHIELDS THE GROUND EQUIPMENT.

A few aspens have been cut from the space in the foreground. July 7, 1918.

FIG. 1.—STATION F-7, PRIOR TO REMOVAL OF LOGS FROM THE GROUND, LOOKING TOWARD UNCUT SPRUCE AND FIR BELOW AND IN THE ADJACENT PLOT WHERE STATION F-9 IS LOCATED. JULY 7, 1914.

FIG. 2.—STATION F-11, FOXPARK, WYO., AT THE SOUTH EDGE OF A THINNED STAND OF LODGEPOLE. AUGUST 9, 1914.

Monument Creek. Other buildings are not close enough to affect the records in any way. The free sweep allowed the prevailing westerly winds probably accounts for some of the phenomenal velocities recorded at this station. In addition, the southward sloping creek valley tends to introduce an air drainage factor in the form of northerly breezes, which are not at all felt on the mountain slopes, and the north and northeast winds accompanying cyclonic storms are also not at all interfered with. Colorado Springs lies 4½ miles from the first abrupt rise of the mountains at Manitou, and 6 miles in an air line from the Fremont Forest Experiment Station.

The equipment of this station is that of a first-class weather bureau station, namely, maximum and minimum thermometers, thermograph, anemometer, psychrometer, sunshine recorder, rain gages, and triple register. No observations of ground or soil conditions are made. The station has been maintained by the faculty and students of Colorado College for about 35 years. The station is principally valuable as forming a base for the whole Pikes Peak series, which extends from this elevation to timberline at 11,500 feet.

D–1: Black Hills western yellow pine.—Elevation, 4,535 feet. Valley situation. Deadwood, S. Dak., is situated in the higher and moister portion of the Black Hills but in a valley surrounded by relatively high ground. It is therefore doubtful whether the station receives greater precipitation than the average for the Black Hills region. The record of precipitation and temperatures has been obtained for a great many years, under a variety of conditions, and while the conditions surrounding the taking of the late record used in this study have not been investigated, it is believed that in distribution of precipitation at least, which is the more important feature, the record will be properly indicative.

Due to artificial influences, the yellow pine forest immediately surrounding this station is far from representative of the Black Hills. However, this locality seems capable of producing the same dense reproduction and the same excellent development of pure yellow pine stands as any other portion of the hills, provided the soil is favorable; but everywhere these qualities seem to be strongly influenced by soils, and especially unfavorably by soils of limestone origin.

F–2: Fremont south slope western yellow pine.—Elevation, 8,921 feet; aspect, S. 35° W.; slope, 34 per cent. This station is situated but 400 feet from the control station, and as it occupies the south exposure of the same main valley it is subject to the same air currents.

The forest is the typical western yellow pine stand of semiarid regions, consisting of not over 20 or 30 trees per acre, with a maximum height of 60 feet. Occasional specimens of limber pine are found, but none of them attains a height equal to that of the yellow pine. The station is quite strongly shaded on the east, but is more open to the south and southwest. This fact, with the southwesterly aspect, accounts for a very late maximum temperature each day, and in part for the high soil temperatures recorded in the morning. (See Pl. II, fig. 1.)

During the two-year period, March, 1910, to February, 1912, this station was visited daily a few minutes later than the control station. As at the control station, all observations except soil temperatures, were made on a tower 20 feet above the ground. During

later years some additional records of ground temperatures and evaporation have been secured for short periods. This station, with the following one, furnished the main part of the data presented in the preliminary report (*3*) on this study.

The full equipment is as follows:

Tower (F–2A):
Maximum and minimum thermometers, in standard shelter, March 1, 1910, to February 28, 1912.
Air thermograph, February 1, 1911, to February 28, 1912.
Anemometer, March 1, 1910, to February 29, 1912.
Psychrometer, March 1, 1910, to February 29, 1912.
8-inch rain gage, March 1, 1910, to February 29, 1912.
Ground (F–2G):
1-foot soil thermometer, in iron pipe, February 10, 1910, to February 29, 1912.
2-foot soil thermometer, in iron pipe, February 10, 1910, to February 29, 1912.
(In addition, these points were observed in spring and fall of 1913, and in 1914 from May to July, when the 4-foot depth was substituted for the 2-foot depth.)
1 and 4 foot soil thermometers, in iron pipes, July 9 to December 12, 1914; March 1, 1915, to February 29, 1916; and May 11, 1917, to September, 1918. On April 26, 1918, a wooden tube was substituted for the iron pipe at the 1-foot depth.
Soil samples at random during growing season July, 1910, to October, 1911.
Soil well in operation during growing seasons after June 29, 1914, and excluding 1916. Regular determinations at 1, 2, and 3 feet, and in 1917 at surface.
Piche evaporimeters, as modified by Weather Bureau, May 5, 1914, to February 29, 1916.
Evaporimeter, inner-cell, Type 4, February to September, 1918; May, 1919, to April, 1920.
Maximum and minimum thermometers, on shielded board, March 2, 1915, to February 29, 1916.

F–3: Fremont Canyon spruce.—Elevation, 8,860 feet; aspect, N. 44° E.; slope, 54 per cent. This station, like the preceding, is only about 400 feet from the control station. It is situated at the foot of a steep northeasterly slope, only a few feet above one of the small streams. (See Pl. I, fig. 2.) It is cut off from the air currents which principally affect Stations 1 and 2 by the westward extension of the ridge on which Station 1 is located, and which becomes considerably higher opposite Station 3. The ground at Station 3 is so close to the stream as to feel very markedly the cold-air stream at night, which on the 20-foot tower is much less apparent.

This type is strictly Engelmann spruce at the station, although as one ascends the slope to a more exposed situation the forest quickly changes to one of Douglas fir. For this reason, in an earlier report (*3*), this station was described as representing a spruce-fir type. The predominance of spruce at the very foot of northerly slopes at this elevation is typical, and the purely local condition should here be considered. The stand has come in since a fire which occurred about 60 years ago.

This station has had the same equipment and has been under observation during the same periods as F–2, with a few insignificant exceptions.

F–4: Fremont east slope pine-fir.—Elevation, 9,117 feet; aspect, N. 88° E.; slope, 27 per cent. This station is placed on a moderate east slope, where it receives the full effect of the morning sun, which, especially during the warmer months, is usually unobscured. The station lies between two very shallow depressions, not over 20 feet

apart, which possibly gives the soil moisture a trifle more than the average value for the slope as a whole. (See Pl. III, fig. 1.)

The site represents a somewhat common condition in the yellow pine forests of the region, which, when not too strongly insolated, give way to Douglas fir as a climax, in agreement with Clements' description (*10*). Here it appears that the succession may have been arrested by the fire which burned over the whole territory about 60 years ago, but on this area merely scarred the mature yellow pine trees. These are now in a decadent condition and somewhat infected by mistletoe, which, through its attacks on the yellow pine saplings, seems to be an important factor in hastening succession. In the tally of the trees within a radius of 50 feet of the station center, it will be noted, the Douglas fir does not hold so prominent a place in the younger reproduction as in the class from 2 to 5 inches in diameter at breast height.

Class.	Yellow pine.	Douglas fir.	Limber pine.
Reproduction under 4.5 feet	20	6	20
Saplings, 0 to 2 inches	15	7	5
Saplings, 2.1 to 5 inches	4	9	5
Trees over 5 inches	17	3	4

The site then is evidently such that the slightest disturbance might cause a swing toward either Douglas fir or yellow pine predominance. The occurrence of considerable aspen (*Populus tremuloides*) and limber pine is not considered significant.

All observations have been taken at or in the ground. The equipment has been as follows:

1 and 4 foot soil thermometers, in iron pipes, July 9, 1914, to December 12, 1914; March 3, 1915, to March 1, 1916; and May 11, 1917, to September, 1920. 1-foot iron pipe replaced by wooden tube, April 26, 1918.

Ground and soil-surface temperatures, May to September, 1920.

Soil well after July, 1914, with soil-moisture samples taken during the open seasons of 1914, 1915, and 1917.

Evaporimeter, inner-cell, Type 4, February to September, 1918, May, 1919, to September, 1920.

F.-5: Fremont Canyon spruce.—Elevation, 9,044 feet; aspect, S. 20° E.; slope, 10 per cent. Conditions here are very similar to those of Station F-3, except that Station F-5 is in the creek bottom, about 10 feet north of the east-west channel. There is no surface stream here, but the underground seepage must be considerable. The soil is alluvial and contains considerable granitic gravel.

The spruce stand forms only a narrow band along the stream channel and the base of the north slope. Aspen reaches better development here, perhaps, than anywhere else in the vicinity. The station is practically at the base of a spruce 18 inches in diameter by 70 feet high. (See Pl. III, fig. 2.) It is strongly shaded except on the southwest, where an artificial opening permits some light to enter. A natural opening also permits sunlight to reach the ground for an hour or more before noon.

The equipment and observations have been the same as for the preceding station.

F-6: Fremont west slope limber pine.—Elevation, 9,060 feet; aspect, N. 48° W.; slope, 32 per cent. Situated near the top of a steep northwest slope, with a wide canyon to the west, this station gets the full sweep of the desiccating winter winds from the west. At this point the slope is less steep than below, and the type is less completely one of limber pine, for it contains some yellow pines, which form the main stand on the ridge just to the east. However, at the station the limber pine strongly predominates. Like all exposed westerly slopes in the Pikes Peak region, this one shows the effect of the winter blasts. The ground is swept bare, and practically no ground cover appears even for short periods in the summer. (See Pl. II, fig. 2). In spite of its apparent poverty, however, the soil at the station was found to contain an unusual amount of fine mineral material and humus. Pure stands of limber pine are extremely rare in the central Rockies, and for this reason the study of the conditions which might have brought this one into being was begun with great interest.

The equipment of Station 6 has all been placed at the ground, as follows:

1 and 4 foot soil thermometers, July 9, 1914, to December 12, 1914; March 3, 1915, to February 29, 1916; and May 11, 1917, to September, 1920. Iron pipe at 1 foot replaced by wooden tube April 26, 1918.

Ground and soil-surface temperatures, May to September, 1920.

Soil well, with moisture determinations for 1, 2, and 3 feet, established July, 1914, and operated during open seasons of 1914, 1915, and 1917.

Maximum and minimum thermometers, in shelter, March 15, 1915, to February 29, 1916.

Anemometer (elevation, 18 inches), March 5, 1915, to February 29, 1916.

Evaporimeter, inner-cell, Type 4, February to September, 1918; May, 1919, to September, 1920.

F-7: Fremont north slope spruce-fir, clear-cut.—Elevation, 9,105 feet; aspect, N. 16° E.; slope 34 per cent. This station is situated near the middle of a north slope whose total width is about 400 feet. It lies 60 feet higher than the stream channel directly below, where Station 5 is situated.

Station 7 is in the lower third of an opening about 250 feet square which was made by clear-cutting the forest. At this level the original stand was a dense mixture of Engelmann spruce and Douglas fir in almost equal proportions, with occasional specimens of limber pine and yellow pine and a few subordinate and decadent aspens. The area was cut over in the fall of 1913, and up to the present there is practically no cover except aspen sprouts, 3 to 5 feet high, and herbs.

This station, together with Stations 8, 9, 14, and 15, represents the conditions on four near-by identical acre plots from which the timber has been cut in different ways. Because of a break in the slope just above the middle of plot 1, two stations, 7 and 8, were thought necessary to represent its soil conditions; but a single station at the center, known as 7–8, was considered adequate for atmospheric measurements. Thus together, Stations 7, 7–8, and 8 are the counterpart of Station 9 in the uncut plot (2) to the east, and of Stations 14 and 15 at the centers of the two additional plots from which only a portion of the timber was removed. These will be described later. It is important to remember that these four stations (or six, considered individually) represent essentially the

FIG. 1.—STATION F-12, WESTERN YELLOW PINE RIDGE TYPE AT THE FREMONT FOREST EXPERIMENT STATION.

In the view are also shown limber pine and Douglas fir saplings, and in the background large Douglas firs. July 7, 1918.

FIG. 2.—STATION F-13, LOOKING SOUTH, SHOWING A PORTION OF THE HIGH ROCKY KNOB WHICH TERMINATES THE RIDGE ON THE EAST. MAY 21, 1915.

FIG. 1.—STATION F-16, AT TIMBER LINE ON PIKES PEAK.

Note that to the west the spruce attains a higher elevation in the shelter of a rocky ridge. October, 1916.

FIG. 2.—FIRST-QUALITY LODGEPOLE PINE IN THE VICINITY OF FRASER, COLO., ON TRANSPORTED SOIL CONTAINING MUCH CLAY. JUNE 3, 1914.

same original conditions, now changed by disturbance of the forest cover. (See Pl. IV, fig. 1.)

At this station the following equipment has been used:

1 and 4 foot soil thermometers, in iron pipes, July 9, to December 12, 1914, and March 3, 1915, to April, 1920, with the exception of March, 1916. 1-foot pipe replaced by wooden tube April 26, 1918.

Soil well in use from July 13, 1914, during open seasons, to end of 1917, weekly determinations being made of moisture at 1, 2, and 3 foot depths, and during 1917 at the surface.

Evaporimeter, Piche, July 7, 1914, to December 12, 1914, and June 8, 1915, to October 24, 1915. Later evaporation records made at Station 7–8.

F–7–8: Fremont north slope Douglas fir, clear-cut.—This station lies midway between Stations 7 and 8 in a clear-cut plot. At this elevation, which is only 16 feet higher than Station 7, the Douglas fir in the original stand was clearly predominant, while at Station 8 it had practically no competition. This location was selected in the center of the clear-cut plot to represent atmospheric conditions for the plot as a whole.

The equipment has been as follows, all placed about 1 foot above the ground:

Maximum and minimum thermometers, on shielded board, September, 1915, to September, 1918, excepting March, 1916.

Air thermograph, on shielded board.
Psychrometer (beginning May 1, 1916).
Anemometer, with register.
Evaporimeter, Type 2, 1916; Type 4, 1917.
} April 1, 1916, to December 31, 1917. Rotated with Stations 14 and 15, this station being reached the first decade of each month.

Evaporimeter, Type 4, January 1, 1918, to April, 1920.

Sunshine recorder, electric thermometric, with register, during first third of each month from July to October, 1917.

8-inch rain gage, April 6, 1916, to December 31, 1917.

F–8: Fremont north slope Douglas fir.—Elevation, 9,137 feet; aspect, N. 22° E.; slope, 26 per cent. The conditions surrounding this station are very similar to those at Station 7, except that the slope to the north is 8 per cent less steep, and Station 8 is at a higher position on the slope. This difference was sufficient to introduce a marked difference in the original forests at the two stations, the forest at Station 8 being almost pure fir, while at Station 7 Engelmann spruce comprised half the stand. The possible insolation of the soil at Station 8 is probably made greater by the nearness of the station to the top of the ridge, with reduced opportunity to secure seepage water and transported soil. The evaporation records of 1914 also indicate that the higher position gives Station 8 somewhat greater exposure to drying influences.

The equipment of this station has been identical with that of Station 7, except that the Piche evaporimeters were used here only during 1914. The conditions recorded here may properly be averaged with those at Station 7 to obtain data representing the clear-cut area as a whole.

F–9: Fremont north slope Douglas fir, uncut.—Elevation, 9,099 feet; aspect, N. 10° E.; slope, 33 per cent. It is seen that this location is practically identical with that of Station 7, except that the slope does not bear quite so much away from the north and is protected by a virgin forest cover, while Stations 7 and 8 are in an artificial opening of the same stand. (See Pl. IV, fig. 1.)

The forest surrounding Station F–9 may be depicted by reference to a tabular statement for an area of 0.942 acres, at the center of which the station is situated. This shows a total of 1,143 trees over 4.5 feet in height, of which 367, or 32.1 per cent, are Douglas firs. The firs comprise 68.6 per cent of all the trees over 4 inches in diameter at breast height, but only 18.8 per cent of those below this size. In contrast, Engelmann spruce comprises only 22.6 per cent of the larger trees, but 47.4 per cent of the smaller ones. This relative status of the two species would indicate, without further evidence, that Douglas fir is unable to hold its own under the dense canopy of the larger trees. That this crowding out of the Douglas fir is not due to lack of seeds, is repeatedly shown by the comparatively large number of fir seedlings which germinate, but soon die. For example, in the new crop of seedlings in 1916 there were 1,183 Douglas firs and only 334 Engelmann spruces. After a few years only about a 3:2 ratio of the two species exists among the small seedlings. In the half-cut plots adjacent, where the canopy is not over one-third as dense, there were practically no spruce seedlings, but there was about the same number of firs. This may be due either to the differences in physical conditions, or to the complete removal of spruce seed trees from the cut-over plots, though it would seem that considerable spruce seed might be blown in. Although fir, because of its control of the canopy, may initiate a large part of the new seedlings each year, there is little doubt that the survivors are mainly of spruce. In other words, the conditions being measured at Station 9 are those conducive to spruce survival.

The equipment of Station 9 has been maintained almost continuously, so that the conditions at Stations 7–8, 14, or 15 might be compared with the conditions at this station, as a secondary control for any period. The record follows. All atmospheric observations have been at an elevation of 1 foot.

1 and 4 foot soil thermometers, in iron pipes, July 10, 1914, to April, 1920, with the exception of March, 1916. 1-foot iron pipe replaced by wooden tube April 26, 1918.

Soil well in use from July 13, 1914, to end of 1917, during open season, giving weekly records of soil moisture at 1, 2, and 3 foot depths, and during 1917 at the surface.

Maximum and minimum thermometers, on tree, September, 1915, to September, 1918, excepting March, 1916.

Air thermograph, under partial shelter, April 1, 1916, to December 31, 1917.

Psychrometer, April 23, 1916, to December 31, 1917.

Anemometer, April 23, 1916, to December 31, 1917, with register most of time.

8-inch rain gage, April 6, 1916, to December 31, 1917.

Evaporimeter, inner-cell, Type 2, April 1 to December 31, 1916.

Evaporimeter, inner-cell, Type 4, January, 1917, to April, 1920.

F-11: Foxpark Plateau lodgepole pine.—Elevation, 9,000 feet; aspect, S.; slope, about 5 per cent. The station is situated within the forest, but only about 50 feet from the edge of it, where it opens out abruptly into a grassy bog or park bordering Foxpark Creek. This station is barely 10 feet above the creek level. As the cover has been considerably lightened by the cutting of trees in the ranger station yard, it is altogether probable that the summer temperatures represent about a mean between those of the dense lodgepole forest and those of the much warmer glades. As winter temperatures are more largely controlled by strong winds and a deep snow blanket, they would be little affected. (See Pl. IV, fig. 2.) The soil at this point

is a decomposed gneiss which forms a grayish, gravelly sand not wholly devoid of clay. On account of the heavy snows which lie until summer, and the presence of the water table at a depth of 6 to 8 feet, the soil is usually saturated during the early part of the growing season, but gradually dries out to a low point. This seems to be true of a considerable area about Foxpark, though the moisture is perhaps greater at the station than in the forest as a whole.

This station is the only one in the lodgepole pine type for which soil data are recorded. It is located very close to Foxpark post office, almost on the line between Colorado and Wyoming, in longitude 106° W. The entire plateau about Foxpark bears an almost unbroken forest of lodgepole of very good quality, but a few high points projecting out of the plateau bear mixed stands of spruce and lodgepole. About 5 miles to the east of Foxpark the plateau breaks off abruptly to the plains, and on these slopes are found a few specimens of yellow pine and Douglas fir.

The Weather Bureau installed maximum and minimum thermometers and an 8-inch rain gage at this station in March, 1911, and the earlier record of temperatures as used in this report is taken directly from Weather Bureau summaries. In March, 1916, the Forest Service supplemented this equipment with the following, which was in use through August, 1918:

Psychrometer.
Anemometer.
Evaporimeter, inner-cell, Type 2. This was replaced by Type 4 evaporimeter, January 15, 1917.
Still earlier, in August, 1914, soil thermometers had been installed, in iron pipes, at depths of 1 and 2 feet, the latter being lowered to 4 feet on March 15, 1916.
A soil well was prepared in July, 1916, and weekly soil samples at the surface and at depths of 1, 2, and 3 feet have been taken during the open season since August 1, 1916.

It is to be noted here that the observations for the Foxpark station have been more or less irregular, owing to the frequent absence of the observer for several days at a time. However, the air temperatures, which would be most affected, have now been observed for a sufficient number of years so that the uncompensated error should be quite small.

F–12: Fremont Ridge western yellow pine.—Elevation, 9,164 feet; aspect, S. 20° E.; slope, 8 per cent. This point is on a broad, well-rounded ridge that has a general east-west bearing, but very little slope for a considerable distance east or west of the station. (See Pl. V, fig. 1.) It is thus very evenly exposed on all sides, and at the outset the exposure to wind from all directions was thought to account largely for the very scrubby growth of the yellow pine.

The stand immediately surrounding the station is, for the most part, young, having probably originated after a fire about 60 years ago. The trees range from a height of about 20 feet down to tiny seedlings. Yellow pine strongly predominates in numbers, but Douglas fir and limber pine are also coming in, and these two species likewise occur in all sizes. The yellow pine was very badly infected with mistletoe, which was seriously retarding the growth of most trees and gradually claiming victims. The elimination of diseased trees during the winter of 1917–18 has markedly improved appearances and the general rate of growth. No cutting was done close to

Station 12. The soil at this site is extremely thin and poor. In fact, there is so little accumulation of organic matter, and the granite is so slightly disintegrated that it can hardly be said that there is any soil.

The equipment of this station consisted of:

Maximum and minimum thermometers, in standard shelter, on the ground, March 3, 1915, to February 29, 1916.

Air thermograph, same location and period.

Anemometer, 8 feet from ground, with register, same period.

Sunshine recorder, electric thermometric, March 7, 1915, to September 10, 1915.

Evaporimeter, inner-cell, Type 4, 1 foot above ground, February 16, 1918, to September, 1920.

1 and 4 foot soil thermometers, in iron pipes, the former from May 22, 1915, and the latter from June 19, 1915, to February 29, 1916. Both from August 1, 1917, to September, 1920. One-foot iron pipe replaced by wooden tube, April 26, 1918.

Ground and soil-surface temperatures, May to September, 1920.

Soil well, furnishing moisture samples at 1, 2, and 3 feet, from July 7, 1915, to end of season, and also surface samples during season of 1917.

F–13: Fremont high-ridge limber pine.—Elevation, 10,300 feet; aspect, flat. This station presents the conditions existing on an exposed ridge at the northeast base of Pikes Peak, where much of the original forest was destroyed by fire many years ago. For the most part this forest was of spruce. Limber pine is now coming in all over the burned area, and in the more sheltered spots the spruce followers are already appearing. At present the stand of limber pine about Station 13 is not sufficient to furnish any protection. The chief characteristic of the site, therefore, is an intense exposure to both sun and wind. (See Pl. V, fig. 2.) It is interesting to note that a few specimens of western yellow pine may be found in the vicinity of this station where the exposure is less severe. Apparently they are of the same age as the first group of limber pines gaining a foothold after the fire. Observations at this point were at 5-day intervals. No soil-moisture determinations were made.

This station was equipped with:

Maximum and minimum thermometers in shelter 5 feet above the ground May 21, 1915, to October 1, 1916.

Air thermograph, same location and period.

Psychrometer.

Anemometer 7 feet above ground. In addition to dial readings at 5-day intervals, the velocity was observed during about an hour for each period from May 21, 1915, to March 5, 1918. Even with this aid, however, it was impossible to determine the 5-day movements with any certainty when high velocities prevailed.

Evaporimeter, wick Type 1, August 26, 1915, to February 11, 1916.

Evaporimeter, inner-cell, Type 2, April 1 to October 1, 1916.

Eight-inch rain gage, May 21, 1915, to October 1, 1916.

Soil thermometers, at depths of 1 and 2 feet in iron pipes, from May 21, 1915, to October 1, 1916.

Soil thermograph, at 1 foot depth, September 1, 1915, to October 1, 1916.

F–14: Fremont north slope Douglas fir, half cut.—Elevation, 9,087 feet; aspect, N. 3° E.; slope, 35 per cent. This station and the following are counterparts of Station 7–8 in clear-cut and of Station 9 in uncut Douglas fir. Station 14 represents conditions under a half canopy of the taller trees of the original stand with all undergrowth removed. The character of the cutting carried out in 1913 was that known to foresters as the "shelterwood system." The

FIG. 1.—ROLLING SAND-HILL LAND, HALSEY, NEBR.

Extreme right of picture corresponds to situation of Station H-3 on southerly exposure.

FIG. 2.—WEATHER STATION AND SURROUNDINGS AT LAKE MORAINE, NEAR PIKES PEAK, COLO. (STATION L-1). AUGUST, 1918.

FIG. 1.—STATION M-1, SHOWING IMMEDIATE SURROUNDINGS OF INSTRUMENT SHELTER.

The soil well is just to the left of the anemometer at the foot of the oak clump. May 23, 1915.

FIG. 2.—WESTERN YELLOW PINE FOREST NEAR PAGOSA SPRINGS, COLO., AT THE FOOT OF AN EAST SLOPE, IN SANDSTONE. APRIL, 1917.

object of this kind of cutting is to leave at the first cut only such trees as will be merchantable in a few years, and these for the value of their protection to the new growth, whose development determines the time when the old trees shall all be removed. Inasmuch as the original stand was not single-aged, though it was mainly so, this process involved forced cutting of material not merchantable except for fuel. All trees except those of Douglas fir were removed in the cutting, and of the latter about 83 trees of an average diameter of 9.7 inches and an aggregate basal area of 43 square feet were left on the acre plot. This represents just one-fourth the basal area of the original stand. Presumably, therefore, the crown density is not over one-fourth of the virgin crown density nor of that now sheltering Station 9.

Although a few observations of minimum temperatures were made at this point in the fall of 1915, the more important records do not begin until 1916. The equipment used was as follows:

Maximum and minimum thermometers, in standard shelter, 1 foot above ground, April 1, 1916, to December 31, 1917.

Air thermograph, in shelter.
Psychrometer.
Anemometer, 1 foot above ground, with register.
Evaporimeter, inner-cell, Type 2, in 1916.
Evaporimeter, inner-cell, Type 4, in 1917.

April 1, 1916, to December 31, 1917. Rotated with Stations 7–8 and 15, this station being reached the second decade of each month.

Evaporimeter, Type 4, January 1, 1918, to April, 1920.

One and 4 foot soil thermometers, in iron pipes, April 1, 1916, to April, 1920; 1-foot iron pipe replaced by wooden tube, April 26, 1918.

Soil well furnishing samples for moisture determination at depths of 1, 2, and 3 feet, from May 23 to end of season, 1916, and also from the surface during the whole season of 1917.

F–15: Fremont north slope Douglas fir, half cut.—Elevation, 9,080 feet; aspect, N. 8° W.; slope, 28 per cent. This station is only 250 feet east of the preceding and practically on the same contour. However, it will be noticed that the slope is slightly less steep, and this location has a very slight bearing to the west of north. The difference in slope, giving somewhat more direct insolation at Station 15 than at Station 14, is probably a little more than counterbalanced, for the general area in which Station 15 is located, by a somewhat greater density of cover. At the station, however, the cover is fairly heavy on the east but relatively open to the west and southwest, permitting sun action in the afternoon, and this will fully account for the slightly higher soil temperatures here than at Station 14.

The plot in the center of which Station 15 lies, like that surrounding Station 14, has been heavily cut over, but with the object here of leaving trees of all sizes, or in other words, of producing a "selection" forest. Again, this cutting was forced, as the original stand was far richer in mature than in immature sizes. This was especially true of the Douglas fir, and as the cutting completely removed all other species, the number of healthy young trees left could not be very great. However, the number of trees is somewhat greater than in the "shelterwood" forest, both of large and small sizes. The principal shortage is in trees 4 to 6 inches in diameter. In the stand left after cutting there are 110 trees of an average diameter of 10.2

inches and 160 trees of an average diameter of 2 inches, making a total basal area of 66 square feet, or 50 per cent more than in the "shelterwood" plot.

The equipment and operation of this station has been the same as of Station 14, except that the periodic use of recording instruments fell here on the third decade of each month.

F–16: Timberline.—Elevation, about 11,500 feet; aspect, N. 10° E.; slope, 40 to 45 per cent. This station represents conditions on the north slope of Pikes Peak, at the upper limits of the Engelmann spruce type, limber pine and bristlecone pine, as well as spruce, being found in the edge of the forest. It is just a few feet outside the timbered zone, which here ends very abruptly. (See Pl. VI, fig. 1.) Presumably, on account of local wind exposure, the point represents one of the lowest dips in the timberline, and was chosen for the observations because of its accessibility.

Owing to the difficulty of the trip, the station has been visited only at 5-day intervals since its installation in October, 1916. For air temperatures such a program necessitates more than the usual dependence upon the thermograph record, as but one correction of the maximum and one of the minimum is secured for each 5-day period. The system has been to apply these corrections to the trace for each day of the five, with slight modification, and then to obtain from the trace the maximum and minimum temperature for each day, calculated from midnight to midnight. This, it is thought, would have permitted no serious error over a long period had the recording thermometers been perfectly reliable. Owing to the high wind velocities it was found impossible to obtain a correct record of minimum temperatures in the shelter where the other instruments were located, and as a final resort two other minimum-registering thermometers were placed on more substantial supports. Although these did not fail to register properly, they did not of course register the temperatures prevailing in the shelter. The entire temperature record, therefore, presents a combination of values, all of which are not representative of the same point, but doubtless represent the locality well enough.

The thermometer shelter, anemometer, and evaporimeter were so placed on a tower that an elevation of about 10 feet above the ground was secured for each instrument. The periodic psychrometer readings, which of course do not have great value, were likewise secured at this elevation. The precipitation record during most of the first year was secured by means of an 8-inch gage placed in the shelter of spruce trees 100 feet from the other equipment. It was thought that the trees afforded no more than enough protection from wind to insure a good snow catch. With rain and little wind, however, it was found that a 12-inch gage in the open gave much higher values. For this reason the entire precipitation record, except for August and September, 1917, is questionable and has not been used. No soil moisture determinations have been made at this station.

The following equipment was used:

Maximum and minimum thermometers, in standard shelter, October 1, 1916, to February 28, 1918.
Air thermograph, in shelter, October 1, 1916, to February 28, 1918.
Psychrometer, in shelter, October 1, 1916, to February 28, 1918.
Anemometer, with register, October 1, 1916, to February 28, 1918.
Evaporimeters, inner-cell, Type 2, October 1, 1916, to December 31, 1916.

Evaporimeters, inner-cell, Type 4, January 1, 1917, to September, 1918.
1 and 4 foot soil thermometers, in iron pipes, October 1, 1916, to September, 1918.
Soil thermograph, October 1, 1916, to October 16, 1917.
8-inch rain gage, under shelter of trees, October 1, 1916, to February 28, 1918.
12-inch tipping-bucket rain gage, with register, August 1, 1917, to September 21, 1918.

F–17: Frances Douglas fir.—Elevation, 9,300 feet; aspect, easterly. This station is situated near Frances, Colo., on a steep mountain side, in the bottom of a gulch opening to the east. The ground in the immediate vicinity of the station is not far from level, but it rises precipitously a few rods to the west. The situation is apparently such as to give marked air-drainage effect at night, and to cause stagnation of the air during the day. The temperature records of this station are thought to have considerable comparative value, because the station is at almost the same elevation as Fremont, and similarly situated on the east slope in the Douglas fir zone.

The forest surrounding the station was at one time a fairly even stand of comparatively small Douglas firs. It has been almost completely destroyed by cutting and fires over a large area, and in this locality there is almost no reproduction. A little higher the granitic and glacial soils are being occupied by lodgepole pine.

F–18: Fraser Basin lodgepole pine.—Elevation, 8,560 feet; aspect, northerly; slope, 1 to 2 per cent. This station, in north-central Colorado, is situated in the broad valley of the Fraser River, which at this point runs slightly west of north. The drainage area to the south of Fraser comprises about 100 square miles, and the valley at this point has widened out into a meadowlike basin of very little slope, having a width of fully a mile between the forest-covered slopes on either side. Although it is thus considerably removed from the forest, there appears no reason for any great difference between the atmospheric conditions over the station and those over the forest. The locality is characterized by precipitation so well distributed over the entire year that, although the month of June is usually about the driest, the melting snow furnishes abundant moisture for the early part of the growing season. The winter temperatures are extremely low, but always accompanied by a good snow blanket. Under these conditions lodgepole pine attains the best development noted anywhere in Colorado, both as to stature of trees and density of stands. (See Pl. VI, fig. 2.)

The character of the soil, considered in connection with the well-distributed precipitation, probably is an important factor in this development. The soil in the forest is of granitic origin but is so thoroughly broken down as to contain a high percentage of clay, and consequently to have a high water-retaining capacity.

The lodgepole forest about Fraser comes down on all slopes practically to the edge of the valley and to an elevation within 100 feet of that of the station; to the south, where the valley is narrower, the forest extends entirely across it. This fact might lead to the conclusion that the forest does not reach the station on account of the forbidding conditions of an alluvial soil. It is also interesting to note that there is no transition zone between the mesophytic conditions of the slopes and the "desert" conditions of the valley. To be sure, a very few specimens of western yellow pine may be found on the lower hills, while somewhat more frequently a clump of

Douglas fir occupies some low, rocky point. The occurrence of Douglas fir seems always to be the result of natural protection from fire, and we may conclude, as in most of the lower lodgepole regions, that Douglas fir originally controlled the situation.

H–2: Nebraska sandhills.—Because of the marked success of the planting of yellow pine and jack pine (*Pinus banksiana*) in the Nebraska sandhills, it has been deemed advisable to observe to what extent the conditions here differ from those of the yellow pine type in the mountains. Since the establishment of the Halsey Nursery in 1903, temperature and precipitation records have been secured in a river-bottom situation (H–1). In October, 1918, an additional primary station (H–2) was established on the hills 80 or 90 feet higher than the river bottom, on a gentle northerly slope. A station (H–3) for the observation of soil temperatures on a steep southeasterly slope was also installed only 200 to 300 feet from H–2. (See Pl. VII, fig. 1.)

In considering the conditions shown by the records for these stations it should be borne in mind that the locality does not produce yellow pine naturally, and that no success has been had from direct seeding. This may be due to the very sandy soil as much as to any atmospheric conditions observed. The latter, apparently, are favorable for a very high growth rate of established trees.

L–1: Lake Moraine Basin spruce.—Elevation, 10,265 feet; aspect, southeast; slope, about 20 per cent. This station is next to the highest in the Pikes Peak series. It is operated by the officials of the city water department of Colorado Springs in cooperation with the Weather Bureau, and the record of precipitation and air temperatures has been obtained for 24 years. This site is on a gentle slope not far from the west bank of Lake Moraine, 20 feet above the water and just outside a thick clump of aspen. (See Pl. VII, fig. 2.) The body of water probably modifies temperature extremes to a slight extent. The station is not protected by forest, for this consists only of scattered specimens of limber pine, 4 to 8 feet high, which followed a destructive fire 60 years ago. Some protection from winter wind is furnished by the steep hill to the northwest.

L–2: Leadville flat spruce.—Elevation, 10,248 feet; aspect, southwesterly; slope, 5 to 10 per cent. The surroundings of this station are on the west, an almost flat bench sloping very gradually to the Arkansas River, 3 miles away, and on the east the higher mountains. The station is near the top of a ridge within the town of Leadville. Most of the ground outside the town is clothed with a young, somewhat open growth of lodgepole pine, which apparently has replaced the virgin forest since the first mining activity in this region disturbed the natural conditions. This, however, has not been closely investigated.

The most striking conditions of the locality are the severe wind exposure afforded by the high elevation and the free sweep over a broad basin to the west, and the apparent poverty of the soil, which is composed of a gravelly sand. This soil, which is of the general character often chosen by lodgepole, may account for the openness of the stands and the not too vigorous growth. On the other hand, openness of the stands may be due to artificial factors, such as smelter fumes, which have been fatal to some of the hill forests nearby.

FIG. 1.—STATION W-A1, WAGON WHEEL GAP, IN NORTH-SLOPE DOUGLAS FIR.
The instrument shelter may be seen just within the timber on left (east) of rock slide. 1910.

FIG. 2.—LOCATION OF INSTRUMENT SHELTER AT STATION W-C, IN BORDERLAND BETWEEN THE FORESTED SLOPE AND THE FLATTER "PARK."

FIG. 1.—SOUTH-SLOPE DOUGLAS FIR, VERY SIMILAR TO THAT AT STATION A-2, WAGON WHEEL GAP.

This photo is at Station B-2. 1910.

FIG. 2.—TYPE OF ENGELMANN SPRUCE FOREST ON NORTH SLOPE STATION W-F, AT 11,500 FEET ELEVATION. APRIL 23, 1913.

The station, of course, does not exactly represent the conditions of the forest. It is thought to be advisable to use the records as showing the conditions at the upper limit of lodgepole growth, in contrast with the more nearly optimum conditions of Nast, on the western slope of Colorado, of Foxpark, on the eastern slope in Wyoming, and of Fraser, in an interior basin.

M–1: Foothills western yellow pine.—Elevation, 7,200 feet; aspect, easterly; slope, 3 to 4 per cent. This station is located at the Monument Nursery, 2 miles west of the railroad station of the same name, and about 20 miles north of Colorado Springs. It may well be compared with other stations in the Pikes Peak series. It represents the foothills type of yellow pine forest, this type being characterized by scrub oak as a secondary cover, which appears to be able to drive yellow pine to the rocky situations, poorer soils, and the banks of eroding gulches.

The station is scarcely more than 100 feet higher than the valley of Monument Creek, which is devoid of forest growth. The pine forest, however, appears on the first hills above the creek. Elsewhere, under similar circumstances, the pine occurs at elevations below 6,000 feet, along ravines and bluffs; hence this station site represents the lower limit of pine growth only as determined by local-topography and soil. The present site of the station is on a flat, east-west ridge or bench about 20 feet higher than the parallel gulch just to the north. Prior to January, 1915, temperature and precipitation records were obtained in this gulch, where cold-air drainage is much more pronounced.

The station is surrounded by oak brush. (See Pl. VIII, fig. 1.) In this brush a few yellow pine seedlings of various ages are making headway. The nearest mature pines stand 40 or 50 feet to the south on an elevated part of the ridge and do not shade the station.

The soil is a very rocky mixture of granitic origin. In the first foot the fragments of granite occupy only a small part of the space, while at a depth of 2 or 3 feet the grayish sandy soil claims only about 60 per cent of the space. The soil contains nearly equal parts of gravel, sand, and finer material. It is evidently a transported soil deposited here before the beginning of the secondary erosion, though its coarse texture suggests glacial rather than water action.

The following equipment has been in use in connection with the daily observations since January, 1915:

Maximum and minimum thermometers, in shelter, 5 feet above the ground.
Air thermograph, until January 1, 1920.
Psychrometer, April 8, 1916, to June, 1919.
Anemometer, on pole, 7 feet above the ground. This height gives some freedom from the protection of the oak brush, most of which is 5 to 7 feet high.
Evaporimeters, Type 2, 5 feet above ground, April 3, 1916, to December 30, 1916.
Evaporimeters, Type 4, 5 feet above ground, January 27, 1917, to date.
Soil thermometers, at depths of 1 and 4 feet, in iron pipes.
Soil well. Samples taken weekly during growing seasons from 1915 to 1918. Sent by mail to Fremont Experiment Station, usually involving about two days in transit before moist weight is taken.
8-inch rain gage.

N–1: Nast western slope lodgepole pine.—Elevation, 8,800 feet; aspect, westerly. This station is situated on the Colorado Midland Railroad between Hagermann Pass and Thomasville, and lies only a few miles west of the highest comb of the Rockies, on a slope

dropping rapidly to the west. It represents a region that once, in all probability, bore a heavy forest of Douglas fir, of which only a few relics remain. The lodgepole pine forest which now clothes the slopes is, for the most part, young and vigorous. No particular study has been made of this locality. The temperature data for the station are introduced simply to show that the temperature conditions conducive to a successful invasion by lodgepole pine are quite uniform throughout the range of the species in this region.

P–1: Southern Colorado western yellow pine.—Elevation, 7,108 feet; nearly flat river valley. Although the pine forest has been almost completely removed from the vicinity of Pagosa Springs, this station may still represent in a fair way the temperature and moisture conditions favorable to the optimum growth of yellow pine in southern Colorado. (See Pl. VIII, fig. 2.) A valley forest about 20 miles from Pagosa is typical of the forest found here. This type is distinctly not the mesa type so characteristic of Arizona and New Mexico. It is a hilly type in which the best development is reached only on the moister ground along stream courses, and the strongly sloping hillsides. The conditions of this region approach those of Arizona in the amount of the winter precipitation, but at corresponding elevations the Colorado type is deficient both in snow and in the volume of the summer rains. It is probably for this reason that the higher, nearly level ground corresponding to the mesas of Arizona bears only a meager stand of pine.

W-A1: Wagon Wheel Gap north slope Douglas fir.—Elevation, 9,610 feet; aspect, north; slope, 40 per cent. This station is one of a series which has been very carefully and consistently operated since 1910, in connection with the stream-flow study conducted by the Forest Service and the Weather Bureau. The meteorological records are of the highest order, although it has not been possible to reach some of the more inaccessible stations for daily observations. The equipment of this station, as of Stations W-D and W-G, has been about as complete as possible. There was, however, no sunshine record, no recording apparatus for anemometer, nor any record of evaporation until August, 1919.

The site represented is a steep north slope bearing in general a Douglas fir stand badly damaged by fire some 25 years ago, and here and there replaced by aspen. (See Pl. IX, fig. 1.) About the instrument shelter there is a fairly dense stand of firs about 40 feet high, but the anemometer and rain gages have been exposed in an opening a few rods to the west where there is an almost bare rock-slide about half an acre in extent. In some places the reproduction is about equally of spruce and of fir, but in general at this elevation the spruce is not of sufficient weight to warrant calling the site a fir-spruce type. On the whole, the struggle between spruce and fir is in almost the same stage as at the corresponding station at Fremont, F–9.

In every respect except that of wind velocity, the records of this station agree so closely with those of W-B1, similarly situated on another drainage area one mile north, that the statement of conditions at the latter point would mean sheer duplication. This similarity gives further assurance that the records fairly represent the type.

The equipment of this station has been maintained essentially in the same status since September, 1910, and is as follows:

Maximum and minimum thermometers in shelter, 8 feet above ground.
Air thermograph, 8 feet above ground.
Hygrograph, 8 feet above ground.
Psychrometer, read daily at 9 a. m.
Anemometer, on post in opening, 4½ feet above ground.
8-inch rain gage, on post in opening.
Marvin shielded gage in opening, since 1913.
1-foot soil thermometer is bulb of telethermoscope having no direct connection with the air above. This has been compared at various times with thermometers in iron, wood, and porcelain tubes. The porcelain tube is retained for frequent checking.
4-foot soil thermometer, in iron pipe, beginning August, 1913.
Soil well, with moisture determinations weekly, at depths of 1, 2, and 3 feet, during open seasons since 1913.

W–A2: Wagon Wheel Gap south slope Douglas fir.—This station is directly opposite A1 on the same watershed, the elevation and slope being almost identical, but the aspect almost south. The stand is here also predominantly one of Douglas fir, but is more open than on the north slope. The trees have attained much larger size. (See Pl. X, fig. 1.) Aspen is restricted to the base of the slope below the station, or to gullies, and only bristlecone pine among conifers competes with the fir. Specimens of the pine are here rare, and become numerous only on the more rocky ground at the top of the slope. Limber pine is relatively rare in the Rio Grande region, and bristlecone pine appears largely to replace it on rocky ground and wind-exposed points.

Although air temperatures were recorded at this station during its earlier years, the longer record covers only soil temperature and soil moisture. The soil temperature at 1 foot has been determined by a thermometer in a wooden tube since January, 1913, and at 4 feet by the one in an iron pipe since October, 1913.

W–C: Wagon Wheel Gap pine-fir.—Elevation, 9,360 feet; aspect, east; slope, 30 per cent. At the initiation of the stream-flow experiment, the point here mentioned was established as a control station with whose conditions those on the two watersheds might be compared. It lies on an east slope between them, and is not affected by forest cover of any kind except as a few aspens form a windscreen for the rain gages. It is, then, spoken of as a pine-fir type only because it lies about on the line between the Douglas fir forest on the higher slopes and the occasional yellow pines which occur on warm, exposed breaks below. (See Pl. IX, fig. 2.) In fact, the soil conditions here, and more markedly on the flatter ground just below, seem to be prohibitive of coniferous growth by reason of the presence of a considerable amount of alkali (carbonate of soda).

The plan at this station has been to measure particularly those conditions which are more or less general for the locality, and which could not be conveniently recorded at points farther from headquarters. The equipment has consisted of:

Maximum and minimum thermometers, in shelter, at 10 feet above ground.
Air thermograph, in shelter, at 10 feet above ground.
Psychrometer.
Anemometer, on tower, about 15 feet above ground, with register.
Wind-vane, on tower, about 18 feet above ground, with register.
Sunshine recorder, electric thermometric, with register.
Tipping-bucket rain gage, 3 feet above ground, with register.

Soil thermometers, 1 foot in wooden tube,[2] and 4 foot in iron pipe.

All records at this station except those for sunshine, rainfall, and soil temperatures were discontinued about the end of 1913.

W–D: Wagon Wheel Gap burned bench spruce.—Elevation, 11,000 feet; aspect, east; slope, 5 per cent. This point is typical of much of the best spruce land in southern Colorado and represents a high, well-watered bench of deep, transported soil, partially protected on the west by a higher ridge and fully open to the sun. (See Pl. XI, fig. 1.) The stand, evidently a very heavy one, was completely killed, probably by the fire which swept this region 25 years ago. The occasional spruce seedlings which have come in do not affect present conditions as measured. The ground is covered by a heavy sod, mainly of sedges. Dead trees, standing and down, furnish considerable protection, but can hardly affect the wind record of the station, which has been taken at a point 20 feet above the ground, in order to eliminate purely local influences.

The station has been equipped with:

Maximum and minimum thermometers, in shelter, about 8 feet above ground, read at 6-day intervals.

Air thermograph, in shelter.

Psychrometer.

Anemometer, on pole 20 feet above ground, connected with register at headquarters.

Eight-inch rain gage.

Tipping-bucket rain gage, connected with register.

Marvin shielded rain and snow gage.

Soil thermometers, 1 foot in wooden tube,[3] and 4 foot in iron pipe, read every 6 days.

Soil well, for moisture determinations, at depths of 1, 2, and 3 feet, every 6 days during open season.

W–G: Wagon Wheel Gap high-ridge spruce.—This station is located at 11,580 feet, on an east-west ridge. The soil thermometers are on ground sloping almost inappreciably to the south. This slope is hardly sufficient to affect any other condition measured. Although the station is within about 500 feet of timberline, and the soil of the ridge is very rocky, the spruce is of remarkably good quality, running up to 70 feet in height, while even on better soils near by it rarely attains more than 80 feet. (See Pl. X, fig. 2, and Pl. XI, fig. 2.)

An opening in the forest of about 1 acre was made in 1913, when this station was established, in order that atmospheric conditions and sunshine might be recorded free from the direct effect of the forest. This record is supplemented by soil temperature and moisture data from Stations E and F, located only a few hundred feet away, at the same elevation, on northerly slopes in the heart of the forest. Stations E, F, and G were abandoned at the end of December, 1917.

The equipment of Station W–G consists of:

Maximum and minimum thermometers, in shelter, 8 feet above ground, read at 6-day intervals.

Air thermograph, in shelter.

Sunshine recorder, operated only during winter season.

Tipping-bucket rain gage, operated only during summer season.

Marvin shielded rain and snow gage.

Soil thermometers, 1 foot in wooden tube,[3] and 4 foot in iron pipe, read every 6 days.

[2] Except when snow becomes deep, when iron pipe with aerial extension is used.

[3] Except when snow becomes deep.

FIG. 1.—LOOKING DOWN ON STATION W-D FROM THE HILL ON THE WEST.
Note small extent of reproduction in this spruce area 25 years after fire. November 5, 1914.

FIG. 2.—STATION W G, IN AN ARTIFICIAL OPENING OF THE HIGH SPRUCE FOREST, RIDGE TYPE, 500 FEET BELOW TIMBERLINE. JULY 28, 1914.

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Soil wells, representative of the high spruce type, were located at Stations E and F, but none here. Moisture determinations every 6 days during open season.

Summary.—In Table 1 is given a summary of the stations which have been enumerated, the arrangement being in the general altitudinal order in which the types appear. Within each group the stations appear in the order of their absolute elevations. Station F–9 has been designated as representing a transition zone between fir and spruce for the reason, already stated, that the conditions under the dense cover here, as shown by the reproduction, are more favorable to the growth of spruce than of Douglas fir. The other stations on the same slope, which are not so heavily shaded, and which seem likely to reproduce to limber pine and fir, have been classed as Douglas fir sites.

TABLE 1.—*List of stations from which data are drawn.*

Vegetative type represented.	Station number.	General locality.	Geographic name.	Elevation.	Character of record.[1]		
					Temperature and precipitation only.	More extensive meteorological.	Soil data.
				Feet.			
Plains	C–1	Pikes Peak	Colorado Springs, Colo.	6,098	.....	x	None.
Western yellow pine.	D–1	Black Hills	Deadwood, S. Dak.	4,535	x	.....	None.
	P–1	Southern Colorado	Pagosa Springs, Colo.	7,108	x	.....	None.
Western yellow pine.	M–1	Pikes Peak	Monument, Colo.	7,200	.....	x	M.&T.
	F–2	do	Fremont Station, Colo.	8,921	.....	x	M.&T.
	F–12	do	do	9,164	.....	x	M.&T.
Limber pine	F–6	do	do	9,060	.....	x	M.&T.
	F–13	do	do	10,300	.....	x	Temp.
	F–1	Pikes Peak (control).	do	8,836	.....	x	M.&T.
Pine-fir	F–4	Pikes Peak	do	9,117	.....	x	M.&T.
	W–C	Rio Grande Valley	Wagon Wheel Gap, Colo.	9,360	.....	x	Temp.
	F–7–8[2]	Pikes Peak	Fremont Station, Colo	9,121	.....	x	M.&T.
	F–17	Northern Colorado	Frances, Colo.	9,300	x	.....	None.
Douglas fir	W–A1	Rio Grand Valley	Wagon Wheel Gap, Colo.	9,610	.....	x	M.&T.
	W–A2	do	do	9,600	x	.....	M.&T.
	F–18	North Central Colorado.	Fraser, Colo.	8,560	x	.....	None.
Lodgepole pine	N–1	Western Slope, Colo.	Nast, Colo.	8,800	x	.....	None.
	F–11	Southern Wyoming	Foxpark, Wyo.	9,000	.....	x	M.&T.
	L–2	Continental Divide, Colo.	Leadville, Colo.	10,248	x	.....	None.
Fir-spruce	F–9	Pikes Peak	Fremont Station, Colo.	9,099	.....	x	M.&T.
	F–3	do	do	8,860	.....	x	M.&T.
	F–5	do	do	9,044	.....	x	M.&T.
Engelmann spruce.	L–1	do	Lake Moraine, Colo.	10,265	x	.....	None.
	W–D	Rio Grande Valley	Wagon Wheel Gap, Colo.	11,000	.....	x	M.&T.
	W–G	do	do	11,580	.....	x	M.&T.
Timberline scrub	F–16	Pikes Peak	Fremont Station, Colo.	11,500	.....	x	Temp.

[1] In the first two columns under this caption the letter x is used as an affirmative sign with reference to the subheadings. In the third column the abbreviation "M. & T." means that both soil moisture and soil temperature data have been secured.

[2] Also F–14 and F–15 under different conditions of forest cover.

THE GROWING SEASON.

In the study which attempts to detail the climatic conditions of a region in relation to vegetation, one can hardly fail to realize the necessity for distinguishing between those conditions which characterize the growing season and those which occur during the period of rest.

In a study of annual or perennial herbs and of deciduous trees it may be possible to draw a fairly sharp line between the growing season and the dormant period, if only on the basis of the period each year in which the plant is in foliage or of that period which is free from killing frosts. With conifers, however, or in fact any evergreen vegetation, the problem is a difficult one; first, because it is next to impossible to determine, in the field, when the period of height or diameter accretion begins and ends; and, secondly, because it is by no means certain that evergreen plants do not lay up carbohydrates necessary for growth whenever light, temperature, and moisture conditions make photosynthesis possible, in winter as well as summer. It is fairly apparent that photosynthetic activity in conifers may occur for short periods of warm winter days. Although we do not know the actual internal leaf temperature necessary for photosynthesis in any plant, it is readily seen, from the melting of the snow, for example, that the leaf temperature may be several degrees higher than that of the air, and that the minimum temperature for photosynthesis may be reached in bright sunlight when the atmospheric condition seems very forbidding. The temperature of light-absorbing bodies, with little wind, may well be as much as 40° F. above that of the air. On January 10, 1918, at 2 p. m. snow was observed melting on the edge of a black shingled roof, where there was reflected as well as direct sunlight, but which was entirely removed from artificial heat, at an air temperature of −6° F. (−21° C.).

From the consideration of such facts it becomes apparent that any "growing season" for evergreen trees or herbs must be set apart on a purely arbitrary basis. We may better speak of a period of maximum or optimum growth, if it is desirable, rather than convey the impression that growth is restricted to the warmer portion of the year. In this bulletin the term "growing season" will be used in this sense.

In the preliminary report (*3*) on this study the writers did not attempt to divide the data between growing season and dormant period, but presented some facts to show that, considering a soil temperature of 41° F. (5° C.) essential to the growth of any of the Rocky Mountain trees, there is a marked difference in the length of the growing season as between different slopes and different forest types. The soil of a south exposure, for example, at a depth of 1 foot was found to be above this temperature for about 220 days, and that of a north exposure for only 133 days. But while there is no occasion for minimizing the importance of this difference the assumption that growth is dependent upon a soil temperature of 41° F. is not substantiated by the facts. The phenological observations of a number of years show that the first swelling of the buds of Douglas fir may occur at soil temperatures as low as 39° F., or as high as 50° F. So far as can be determined by this crude method of observation, soil temperature and moisture are strongly interdependent, and it is the molecular activity of the soil water, as determined by its temperature and amount, and as well by the solutes it contains, which controls the beginning of new growth.

The time at which the first growth of a given tree may be noted in successive years is so variable as to make the fixing of even a mean date almost impossible. When the variations between different sites and elevations and the different species on the same site are brought into the problem it becomes so involved that its significance is likely to be obscured.

For all of the above reasons it has been decided to consider the "growing season" as synonymous with "summer," or the months of June, July, and August, and the first decade[4] in September. The three months stand quite apart from the remainder of the year. At the low elevations, of course, much vegetative activity begins before June 1; at very high elevations deep banks of snow remain until after July 1. But at all elevations in or very close to the high mountain ranges the cooling effect of a general snow covering disappears soon after June 1, and this causes a very abrupt change in the temperature conditions. The first decade of September is included because it is nearly always as warm as if not warmer than the much cloudier decade preceding. Thus a comparison of temperatures for these 10 decades may be quite as valuable as a comparison of mean temperatures or temperature sums for growing seasons of variable length, as we have practically no knowledge of what temperatures are growing temperatures for the plants under consideration. It may be said quite safely for the limited latitudinal range covered by this discussion that, if the summer temperature of a given site is found to be relatively high, the season during which it has favorable temperatures for growth must also be relatively long. It is therefore thought worth while in this bulletin to give summer or "growing season" means for all data, as well as annual means. Any greater refinement of the distinction between periods of growth and rest does not appear justified.

ABSOLUTE AND COMPARATIVE CONDITIONS IN THE VARIOUS FOREST TYPES.

AIR TEMPERATURES.

In taking up the study of atmospheric conditions which may cause the differentiation of mountain forests into types dominated by different species it is natural to turn first to the subject of air temperatures for two reasons, viz:

(1) The decrease in temperature with an increase in altitude is the most obvious change which occurs between plains and mountain tops, and hence has the appearance, at least, of being a primary cause for the zonal distribution of each species of the forest. The difference in the warmth of north and south exposures is equally perceptible and suggests a primary cause for the difference in forest cover which usually characterizes opposing slopes at the same elevation.

(2) Air temperatures are more readily measured, perhaps, than any other conditions, and this has given rise to more records of air temperatures than of other conditions except possibly precipitation. This fact makes it possible to draw upon several localities besides

[4] Throughout this bulletin the term "decade" is used to denote a third of a month, ordinarily a period of 10 days, but varying from 8 to 11 days when the last decade of a month is referred to.

those especially covered by the present study in considering air temperatures of the various forest types.

As already stated, the air temperature observations in this study fall into two groups, namely, (1) those referring to conditions several feet (4½ or more) above the ground, and hence more or less representative of an extensive locality; and (2) those applying to conditions within a foot of the ground and reflecting the local influences of insolation and radiation. Data of the second class will be referred to as "ground temperatures" and are available for only a few of the special stations where the conditions directly affecting forest reproduction seemed very important.

By agreement the mean temperature for any period of 24 hours may be computed by adding the highest and lowest temperatures in that period and dividing the sum by 2. It is well understood that for any single period this method is not at all likely to give a true mean temperature. But common experience shows that over a number of daily periods (for example, a month) the mean temperature so computed will be practically the same as the mean computed from hourly temperatures. The latter, of course, can be had only where a thermograph is employed, and to make use of the many records obtained from maximum and minimum registering thermometers it is necessary to employ the simpler method. It seems desirable, therefore, to keep all records to the same standard, even where hourly temperatures might be secured from thermograph traces.

In addition to the convenience of the method the mean temperature derived from the maximum and minimum temperatures has this virtue—that it involves no element of judgment in the computation. Without going into the mechanics of the thermograph, it may simply be said that the correction to be applied to different portions of a thermograph trace can not properly be determined by rule-of-thumb as is usually done. The character and amount of such corrections must rest upon the question of whether or not the observable errors in the trace are due to the natural inertia of the instrument or to improper adjustment of its mechanism. Hence slightly variable results may be obtained in reading hourly temperatures from the thermograph trace, and this fact detracts greatly from the value of hourly records as ordinarily prepared.

The temperature records of the control station at Fremont have been prepared by computing the maximum and minimum temperatures for each midnight-to-midnight period from the thermograph trace as corrected from thermometer registrations. The daily range is the difference between the highest and lowest temperature from one midnight to the next and the daily mean the average between the highest and lowest temperatures. To obtain records for other stations exactly comparable with the control station as to period, the same method has been followed where thermograph traces made it possible. For those stations having no thermographs the method has always been to make observations in the morning, tabulating the minimum temperature as of the day on which recorded and the maximum temperature as of the day previous.

Temperatures at the control station.—The air-temperature record for the control station, representing atmospheric conditions 20 feet above the ground and in all probability mean conditions for this elevation (8,836 feet) and locality, little affected by local exposure and other circumstances, extends from January, 1910, to April, 1921, inclusive, with the exceptions already noted. For the most part these records were compiled and comparisons between the types were made on the basis of data secured to the end of March, 1918. Such comparisons seem quite adequate but to arrive more nearly at normal absolute temperatures records secured since March, 1918, will sometimes be used. The constant use of a thermograph and of standardized thermometers has made this a very satisfactory record. It has been very carefully checked over since its compilation, as secured month by month, so that little error is likely to remain in it except that inherent in the short method of computing means.

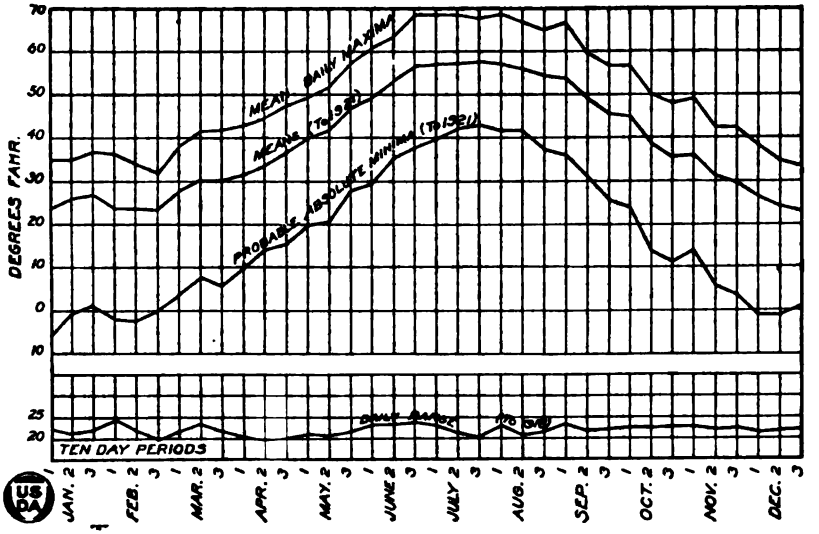

FIG. 1.—Air temperatures at control station by 10 day periods. (F-1) Elevation 8,836 feet.

Mean air temperatures.—The complete record of mean air temperatures for the control station is given in Table 2, by decades and months, for the purpose of showing the possible variation in corresponding periods of different years, as well as the constancy of certain conditions which are of interest. The average temperatures are shown in Figure 1.

NOTE.—All original records of air temperatures for decades, months, and years are carried to two decimal places. Hence, some of the means given in the following tables, do not agree precisely with the 1-place figures from which they are apparently derived. In dropping hundredths to save space in these tables, the rule is followed of throwing 0.05 to the nearest even tenth. Thus 0.45 becomes 0.4 and 0.55 becomes 0.6.

TABLE 2.—*Mean air temperatures at the control station (20 feet above the ground).*[1]

Year.	Decade.	Record by decades and months in degrees Fahrenheit.												Annual.	Mean growing season.
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
1910	1	17.6	18.7	36.9	35.6	39.9	53.1	58.8	58.3	56.4	50.4	39.5	33.7	.....	.....
	2	28.4	15.6	38.3	36.5	40.2	58.3	63.0	57.6	55.7	42.4	31.2	30.8	.....	.....
	3	31.0	28.2	38.6	43.1	46.3	57.4	61.8	56.6	49.7	39.8	37.7	22.2	.....	.....
	Month	25.8	20.3	37.9	38.4	42.3	56.3	61.2	57.4	53.9	44.1	36.1	28.7	41.88	58.12
1911	1	24.4	29.1	35.6	36.5	44.9	56.3	55.3	59.2	54.3	45.1	29.2	30.2	.....	.....
	2	36.4	21.6	30.7	31.5	45.7	53.2	55.3	61.2	52.6	36.8	32.0	14.4	.....	.....
	3	33.6	11.2	32.1	39.5	47.0	58.8	54.0	51.7	53.1	31.0	22.7	14.9	.....	.....
	Month	31.5	21.3	32.8	35.8	45.9	56.1	54.8	57.2	53.3	37.4	28.0	19.7	39.49	55.92
1912	1	19.4	23.7	24.2	35.4	38.7	50.3	55.9	54.9	54.5	42.6	36.2	19.8	.....	.....
	2	28.2	23.2	25.3	28.7	39.5	43.4	56.8	54.5	39.5	40.6	35.4	24.5	.....	.....
	3	29.8	14.2	23.3	34.2	51.1	52.1	57.4	58.3	36.0	34.4	30.4	20.6	.....	.....
	Month	25.9	20.6	24.3	32.8	43.4	48.6	56.7	56.0	43.3	39.0	34.0	21.6	37.18	53.80
1913	1	13.6	18.4	26.7	31.1	39.4	46.2	62.3	59.6	54.6	41.6	36.5	24.0	.....	.....
	2	23.9	22.6	24.7	40.6	45.2	52.2	56.8	58.9	45.0	35.2	39.2	24.6	.....	.....
	3	27.1	12.2	28.4	38.4	51.4	56.0	53.4	57.3	37.0	31.3	30.5	21.1	.....	.....
	Month	21.7	18.1	26.7	36.7	45.5	51.5	57.4	58.6	45.6	35.9	35.4	23.2	38.02	55.73
1914	1	32.0	.....	.....	30.3	42.0	52.1	54.1	58.2	56.4	45.1	40.8	.....	.....	.....
	2	31.3	.....	.....	34.0	39.0	53.6	57.1	59.6	52.7	42.9	31.6	.....	.....	.....
	3	.....	.....	.....	36.5	49.3	57.0	56.8	53.4	48.9	39.0	34.7	.....	.....	.....
	Month	.....	.....	.....	33.6	43.6	54.2	56.0	57.0	52.7	42.2	35.7	.....	.....	55.82
1915	1	.....	.....	16.2	34.5	32.4	44.2	53.0	52.6	52.9	41.9	41.4	34.1	.....	.....
	2	.....	.....	23.3	38.3	42.7	50.3	57.2	51.8	49.2	37.5	25.6	22.3	.....	.....
	3	.....	.....	28.0	39.9	42.6	51.3	53.6	51.3	46.3	47.5	29.2	23.4	.....	.....
	Month	.....	.....	22.7	37.6	39.3	48.6	54.6	51.9	49.5	42.5	32.1	26.5	.....	51.83
1916	1	31.9	24.9	30.8	28.4	44.3	46.8	59.9	58.1	55.4	45.3	38.1	24.7	.....	.....
	2	18.3	33.8	40.8	36.4	35.1	52.0	57.5	55.8	44.8	35.4	19.8	18.4	.....	.....
	3	21.4	27.2	31.7	36.8	48.8	58.6	59.7	51.0	47.0	37.7	28.1	15.9	.....	.....
	Month	23.8	28.7	34.4	33.9	42.9	52.5	59.1	54.8	49.1	39.4	28.6	19.5	38.89	55.48
1917	1	28.1	24.1	18.2	27.6	27.7	45.7	56.5	57.0	55.9	46.9	40.2	23.4	.....	.....
	2	17.0	22.0	20.1	32.8	42.6	51.2	57.4	51.4	49.0	40.0	33.6	33.6	.....	.....
	3	19.8	27.4	28.7	32.8	36.8	59.8	61.6	53.0	47.9	31.9	35.3	35.3	.....	.....
	Month	21.5	24.3	22.5	31.0	35.7	52.2	58.6	53.8	51.0	39.3	36.4	30.9	38.11	54.95
1918	1	23.7	28.2	33.0	28.6	42.7	52.2	56.1	59.1	47.2	.....	.....	.....	.....	.....
	2	11.2	22.4	33.9	28.0	44.2	61.0	54.8	55.8	47.4	.....	.....	.....	.....	.....
	3	18.0	32.2	34.7	34.5	46.0	56.5	57.0	54.4	.....	.....	.....	.....	.....	.....
	Month	17.7	27.2	33.9	30.4	44.4	56.5	56.0	56.4	.....	.....	.....	.....	.....	55.36
1919	1	.....	.....	.....	.....	39.1	41.9	60.0	57.0	57.9	38.4	31.4	21.8	.....	.....
	2	.....	.....	.....	.....	43.6	54.5	57.5	58.9	52.0	37.1	33.6	28.2	.....	.....
	3	.....	.....	.....	.....	46.6	59.2	60.0	60.2	46.8	34.0	25.1	35.5	May-	April.
	Month	.....	.....	.....	.....	43.2	51.8	59.2	58.8	52.2	36.4	30.1	28.7	39.01	56.70
1920	1	19.4	28.0	21.6	28.1	45.3	51.8	58.2	58.1	48.5	53.4	30.3	29.9	.....	.....
	2	36.0	24.0	25.8	27.8	39.0	52.1	60.1	53.0	59.8	43.2	29.5	24.1	.....	.....
	3	33.9	20.7	29.2	27.5	51.1	56.6	61.3	52.9	47.8	32.0	28.8	21.7	May-	April.
	Month	29.9	24.4	25.6	27.8	45.3	53.5	59.9	54.6	52.0	42.5	29.6	25.1	40.56	55.25
1921	1	27.5	21.3	34.6	31.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	29.3	28.0	40.3	33.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	28.9	37.3	28.7	34.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Month	28.6	28.2	34.3	33.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	1	23.8	24.0	27.8	31.6	39.7	49.1	57.3	57.5	54.0	45.1	36.4	26.8	.....	.....
	2	26.0	23.7	30.3	33.4	41.5	52.9	57.6	56.2	49.8	39.1	31.2	24.5	.....	.....
	3	27.1	23.4	30.3	36.1	47.0	56.7	57.9	54.6	46.0	35.9	30.2	23.4	.....	.....
	Month	25.7	23.7	29.5	33.7	42.9	52.9	57.6	56.0	49.9	39.9	32.6	24.9	39.11	55.35

[1] See Note, p. 29.

The following points in Table 2 are worthy of note: (1) In all but the summer months, temperatures in consecutive decades are subject to very radical changes. Even the mean monthly temperatures are very dissimilar in different years, and, in any one year, for example, April may be cooler than March. Such discrepancies point to the need for a long record to insure even approximate "normals" for any given period, but more particularly in this study to the absolute necessity for comparing temperatures of different stations for identical periods only.

(2) The first decade of June is seen to attain a temperature of almost 50° F., and temperatures above 50° F. prevail from then until after the first decade of September. It will later be seen that these ten decades, except the first one, are also free from the liability of frost. They form, then, a fairly logical as well as convenient basis for separating the growing season from the remainder of the year, at least at this middle elevation. In other localities the winter snow may remain considerably after June 1, and this necessarily means a shortening of the frost-free period for all adjacent areas.

(3) The highest temperatures occur from the middle to the end of July. Thereafter the probability of cloudiness and rain increases, until about September 1, when a rise in temperature may again occur with clear weather. It will be noted that in 5 years out of 11, this first decade of September is markedly warmer than the last of August Thus, while much of the temperate United States is feeling its most oppressive heat in August, the mountain area subject to the "summer rainy spell" avoids any excess at that time. The cloudy weather depresses the minima quite as much as or possibly a little more than the maxima, which may be reached, on many rainy days, before the afternoon clouds gather. That the minima are not held up is evidently due to the quick clearing away of the clouds and to the rapid evaporation after each shower.

It will be noted that the normally highest decade has a temperature of only 58° F. and that the highest single decade of record showed a temperature of only 63° F. (July, 1910). Detailed examination of the records shows only a few individual days attaining to the height of 66° F., which, according to Baker (*1*), is approximately the mean summer temperature required for the proper development of corn. The failure of the mountains to produce agricultural crops is, on this basis alone, quite fully explained.

(4) The winter temperatures are not extremely low. The total range from summer to winter temperatures is, in fact, much less than in the lowlands of the northern United States, and the winter temperatures are actually higher in the mountains. It will later be shown that they are somewhat higher in the Pikes Peak region than elsewhere at corresponding elevations. This fact alone augurs unfavorably for vegetation, and especially for vegetation which retains its foliage through the winter. When, however, it is noted that the lowest winter temperatures are synchronous with periods of calm (February), and the warmer periods always associated with high westerly descending winds, the full importance of this period begins to be apparent. The table shows that the temperatures do not decrease in normal fashion to about February 1, but reach practically their lowest point at the end of December, then rise during the January windy period, to find a second depression in the calm of February

and again an unseasonable rise with the recurring winds of March. April brings much less wind and the heaviest snows; hence the low temperatures.

(5) The autumn temperatures contain little of interest unless it be in the somewhat sharp depressions for the second decade of September and the second of October, which are very often periods of heavy, wet snows.

Range of air temperatures.—It is very doubtful whether the range of air temperatures is of much biological significance, at least in connection with plants so "hardy" and so accustomed to a great variety of conditions as the coniferous trees. For this reason it seems necessary only to show the normal values, by decades, as computed up to March, 1918. (Table 3). These have a value also in connection with the table of mean temperatures in indicating the maxima and minima, which may be directly computed by use of the two tables and which, therefore, will be omitted.

Table 3 shows that the mean daily range at the control station is 22.3°; and, although it varies for individual decades by as much as 7° and is greatly influenced by cloudiness, wind, and other circumstances, the maxima and minima, respectively, may be approximated if 11° are added to or subtracted from the mean temperature for any period.

TABLE 3.—*Mean daily range of air temperatures at the control station (averages to March, 1918).*

Decade.	Record by decades and months in degrees Fahrenheit.												Mean annual.	Mean growing season.[1]
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
1	22.5	24.4	21.9	20.9	21.2	23.6	23.3	23.4	23.4	23.2	23.6	22.2	.....	.....
2	21.2	22.0	23.2	19.6	20.8	23.7	21.8	21.4	22.2	23.0	22.6	22.5	.....	.....
3	22.2	19.8	22.0	20.4	21.8	24.4	20.9	22.1	22.4	23.5	23.0	23.1	.....	.....
Month	22.0	22.2	22.3	20.3	21.3	23.9	22.0	22.3	22.7	23.2	23.1	22.6	22.32	22.80

[1] See note, p. 29.

From the purely meteorological standpoint, the shortening of the daily range in the stormy period of April is of some interest. Of even greater interest is the decrease during the windy winter months, which does not show up in the means because here the action and reaction are about equal. A west wind may have any one of several effects on the temperature curve, but nearly always gives it an abnormal shape, because the wind rarely attains its greatest force during the warmer part of the day. Arising in the evening, after a cloudy day, it may bring the maximum temperature at midnight. If the following day witnesses a dying of the wind, its maximum temperature may be recorded at the beginning and its minimum at the end of the midnight to midnight period. A steady wind may hold the daily range down to 8° or 10°, but a sudden rise or cessation will elevate it to 40°. There are, of course, other cosmic conditions at the source of such winds, which accentuate their effect on temperature.

From the average values it is seen that the daily range is slightly greater during the growing season than for the year as a whole. However, only the year 1910 shows this character in a marked degree. If this year were eliminated, the growing season and annual means would be almost identical. The peculiarity of the season of 1910 deserves consideration. The very high mean temperatures for that year, as well as the high daily ranges, it was at first conceived, might have been due to some condition in the exposure of thermometers which was later altered. However, no such factor could be recalled except that during 1910, and 1911 as well, extra observations were taken at 1 p. m., and the opening of the shelter at that hour very frequently resulted in a slight jump of the thermometers and thermograph. Allowance was always made for this when the maximum at this moment exceeded that of any other hour, which it rarely did. On examining all the conditions for 1910, however, it is found that that year was one of the driest on record, both as to precipitation and atmospheric humidity, and had a very high percentage of sunshine. As these conditions are associated with great daily ranges for short periods, so they may be seen to account for the general character of the year 1910, and for the somewhat high ranges of 1917.

Absolute minimum air temperatures.—The Pikes Peak region is not subject to extremely low temperatures in winter, even for short periods, nor is it evident that where very great extremes do occur, in other parts of the central Rockies, they have any but a beneficial effect on established forests. However, a discussion of minimum temperatures (Table 4) is of interest in connection with forest reproduction, especially in a locality where late germination is induced by especially favorable conditions in July and August. Pearson (*16*) concluded that young reproduction of yellow pine is extremely susceptible to frost injury, and indeed there is evidence to indicate that lodgepole pine, spruce, and Douglas fir seedlings succumb to fall frosts if they are not fully matured. The forester is in the habit of saying that the seedling must be "lignified," that is, its tissues must be solidified, before it can withstand freezing. It would probably be more correct to say that it is necessary for the young plant to carry on photosynthesis and by the accumulation of soluble carbohydrates make the sap so dense that it will not freeze with the first frost or freeze firmly at any temperature. Lignification would naturally be an immediate sequel to this accumulation of building material.

In Table 4 the lowest temperature for each decade of the record has been set down, and these temperatures have been averaged at the foot of the table in such a way as to show the probable (not the possible) minimum for any period of the year, in so far as a record of this length may indicate probabilities. Because of very unusual occurrences since March, 1918, it has seemed desirable to extend this record to April, 1921. The data recorded since May, 1920, are for a site where the probable minimum appears to be 1° to 2° higher than at the control station. However, this will not affect the averages more than 0.1° or 0.2°, and the additional record assists in eliminating irregularities.

TABLE 4.—*Absolute minima at the control station (20 feet above ground).*

Year.	Decade.	Record in degrees Fahrenheit by decades and months.												Annual.	Growing season.
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
1910	1	−14.0	− 3.0	10.1	12.5	19.0	30.5	40.0	40.0	36.0	24.0	16.5	8.0	.....	.....
	2	7.0	−20.5	20.5	11.0	17.0	39.0	42.0	41.0	36.0	5.0	11.0	13.0	.....	.....
	3	8.0	6.5	10.5	25.0	24.5	37.0	43.0	28.5	32.0	11.0	9.0	2.0	.....	.....
	Month	−14.0	−20.5	10.1	11.0	17.0	30.5	40.0	28.5	32.0	5.0	9.0	2.0	−20.5	28.5
1911	1	−22.5	8.0	16.5	13.0	20.0	36.0	39.0	36.0	33.5	28.0	0.5	4.2	.....	.....
	2	15.0	−10.5	13.0	9.5	21.0	37.0	42.0	45.0	29.0	−1.0	− 2.5	− 4.5	.....	.....
	3	4.0	−11.0	6.0	19.0	26.0	41.5	40.0	34.5	33.0	8.0	− 2.0	− 6.0	.....	.....
	Month	−22.5	−11.0	6.0	9.5	20.0	36.0	39.0	34.5	29.0	−1.0	− 2.5	− 6.0	−22.5	33.5
1912	1	− 4.5	− 2.0	− 1.0	15.0	21.0	30.0	33.0	38.0	33.5	25.0	15.9	− 6.5	.....	.....
	2	2.5	3.0	− 1.0	17.0	21.0	25.0	42.5	42.0	22.0	22.0	17.5	− 4.0	.....	.....
	3	6.4	− 7.0	3.5	11.5	30.2	32.5	45.0	41.5	17.0	14.0	− 2.5	− 4.5	.....	.....
	Month	− 4.5	− 7.0	− 1.0	11.5	21.0	25.0	33.0	38.0	17.0	14.0	− 2.5	− 6.5	− 7.0	25.0
1913	1	−23.0	− 8.0	11.0	10.0	22.0	34.5	42.0	41.5	39.0	20.0	14.5	7.7	.....	.....
	2	− 3.5	− 4.2	− 2.0	16.5	28.0	36.0	41.0	43.5	26.0	13.2	21.5	1.7	.....	.....
	3	8.0	− 8.5	− 7.0	10.0	29.0	38.0	38.0	43.5	18.5	5.6	14.4	0.0	.....	.....
	Month	−23.0	− 8.5	− 7.0	10.0	22.0	34.5	38.0	41.5	18.5	5.6	14.4	0.0	−23.0	34.5
1914	1	6.5	.....	.....	5.3	22.5	35.5	40.6	42.1	34.0	25.8	22.0	.....	.....	.....
	2	7.5	.....	.....	12.0	24.0	37.8	43.0	43.2	32.0	18.4	3.5	.....	.....	.....
	3	.....	.....	.....	18.4	38.0	41.5	44.5	39.1	28.0	24.2	15.9	.....	.....	.....
	Month	.....	.....	.....	5.3	22.5	35.5	40.6	39.1	28.0	18.4	3.5	.....	.....	34.0
1915	1	.....	.....	2.0	17.0	13.3	23.2	33.5	37.8	36.0	18.0	21.7	9.7	.....	.....
	2	.....	.....	− 0.3	26.0	17.6	30.1	41.7	39.2	30.3	21.9	− 1.2	1.0	.....	.....
	3	.....	.....	7.5	28.1	24.8	36.7	42.0	35.4	30.0	25.2	− 0.9	− 5.5	.....	.....
	Month	− [1]20	.....	− 0.3	17.0	13.3	23.2	33.5	35.4	30.0	18.0	− 1.2	− 5.5	−20.0	23.2
1916	1	10.0	−16.6	0.4	6.7	11.0	29.8	45.0	44.4	37.0	26.0	12.3	− 9.3	.....	.....
	2	− 9.1	14.5	11.4	15.5	12.0	34.7	43.0	41.6	27.6	6.2	−18.1	− 7.8	.....	.....
	3	−15.3	8.5	9.6	12.1	29.3	36.0	45.3	36.5	23.4	14.7	4.2	− 5.5	.....	.....
	Month	−15.3	−16.6	0.4	6.7	11.0	29.8	43.0	36.5	23.4	6.2	−18.1	− 9.3	−18.1	29.8
1917	1	11.4	−14.7	−11.0	2.7	11.7	24.1	39.0	41.6	38.8	24.4	22.6	− 5.8	.....	.....
	2	−16.0	0.7	0.6	18.0	20.0	32.7	40.4	40.4	32.7	7.9	18.2	6.0	.....	.....
	3	−14.0	2.5	0.4	7.6	22.3	40.2	46.3	36.1	27.7	−6.8	14.4	18.0	.....	.....
	Month	−16.0	−14.7	−11.0	2.7	11.7	24.1	39.0	36.1	27.7	−6.8	14.4	− 5.3	−16.0	24.1
1918	1	−22.5	− 3.8	14.5	12.6	18.2	32.0	40.0	41.1	31.0	.....	.....	.....	.....	.....
	2	−10.7	− 4.0	6.5	5.0	21.4	46.2	40.6	44.2	29.0	.....	.....	.....	.....	.....
	3	− 9.4	− 4.6	15.5	17.8	28.3	34.1	40.5	36.7	.....	.....	.....	.....	.....	.....
	Month	−22.5	− 4.6	6.5	5.0	18.2	32.0	40.0	36.7	.....	.....	.....	.....	−22.5	31.0
1919	1	.....	.....	.....	.....	26.7	18.7	44.1	44.8	42.9	16.1	9.7	−26.2	.....	.....
	2	.....	.....	.....	.....	26.6	37.7	44.9	43.3	36.6	20.6	11.0	−10.0	.....	.....
	3	.....	.....	.....	.....	23.9	43.7	44.3	43.8	26.8	7.1	−15.9	14.0	.....	.....
	Month	.....	.....	.....	.....	23.9	18.7	44.1	43.3	26.8	7.1	−15.9	−26.2	−26.2	18.7
1920	1	− 6.5	13.0	−11.2	−2.8	30.4	30.8	40.8	47.0	36.8	35.5	9.4	13.2	.....	.....
	2	− 2.6	− 3.5	8.0	11.1	17.8	36.3	45.4	38.0	46.6	26.5	9.2	0.0	.....	.....
	3	11.2	0.4	7.9	7.1	31.0	38.2	46.0	37.1	27.6	11.8	7.9	− 1.0	.....	.....
	Month	− 6.5	− 3.5	−11.2	−2.8	17.8	30.8	40.8	37.1	27.6	11.8	0.2	− 1.0	−11.2	30.8
1921	1	4.5	3.2	3.7	9.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	0.5	1.5	19.0	9.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	10.2	10.0	8.2	13.7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Month	0.5	1.5	3.7	9.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average probabilities	1	− 6.0	− 2.7	3.5	9.2	19.6	29.6	39.7	41.3	36.2	24.3	14.5	− 0.5	.....	.....
	2	− 0.9	− 2.6	7.6	13.7	20.6	35.7	42.4	41.9	31.6	14.1	6.1	− 0.5	.....	.....
	3	1.0	− 0.4	6.2	15.5	27.9	38.1	43.2	37.5	26.4	11.5	4.4	1.3	.....	.....
	Month	−14.4	− 9.4	−0.4	7.8	18.0	29.1	39.2	37.0	26.0	7.8	0.1	− 6.4	−18.7	28.5

[1] Minimum for the period from December to February, inclusive.

The probability of freezing temperatures in the first decade of June has already been mentioned in the discussion of the "growing season." Nevertheless, it is difficult to see how the factor of frosts at this time can have much effect on the problem of what causes the survival of one species and the failure of another. New seedlings have rarely appeared at this time, and those from previous seasons which have survived the winter should hardly be susceptible to injury at so late a date. New growth on older trees will barely have started by June 10, and shows no injury from the snows which may occur at this time. Even young aspen leaves just emerging from the bud withstand temperatures considerably below 32° F. without apparent injury. Observation at a more advanced stage has not yet been possible. The great certainty of freedom from frost in the first decade of September fully justifies extending the growing season over this period. The second decade is equally certain to record a thorough freezing.

The lowest temperatures of the year are almost certain to be recorded in January, notwithstanding the fact that the lowest mean temperatures occur in February. This is made possible by the fact that the absolute minima fall in periods of calm, when the protection (if such it may be called) of the westerly winds is temporarily withdrawn. It will later be seen that the high, rather than the low, temperatures of January have the greater significance.

Classification of days according to temperature.—The computation of mean temperatures even for so short a period as a decade tends to hide the fluctuations and smooth over the extremes. In a biological study it may be of interest to know, for example, that in a January having a mean temperature of 17.7°, whose warmest decade was 23.7°, there might be two days having mean temperatures above 41°, and to consider whatever possibilities this may present in the matter of the photosynthetic activity of trees, and also the more important probability of damaging transpiration.

Therefore, to present most strikingly the temperature conditions at the control station, Table 5 has been prepared, showing for each month up to March, 1918, the number of days of the following arbitrary classes, based on mean temperatures:

No thawing: Mean and maximum, 32.0° F. or less.
Freezing: Mean below 32°, and maximum above 32°.
Cold: Mean temperature, 32.1° to 41°.
Cool: Mean temperature, 41.1° to 50°.
Moderate: Mean temperature, 50.1° to 60°.
Warm: Mean temperature, 60.1° to 72.°

It should, of course, be realized that thawing or melting of snow is not precluded on days whose maximum air temperatures are below 32 degrees. In bright sunlight, thawing may take place with temperatures as low as 0° F.

TABLE 5.—*Classification of days according to air temperatures.*

Year.	Class.	Record by months in degrees Fahrenheit.												Total annual.	Total growing season.
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
1910	No thawing	11	14	2	2	2	0	0	0	0	3	2	6	42	.....
	Freezing	10	9	3	3	3	0	0	0	0	1	8	13	50	.....
	Cold	7	5	15	17	5	0	0	1	1	4	9	12	76	1
	Cool	3	.....	11	6	15	4	1	1	5	11	10	.....	67	7
	Moderate	.....	.....	.....	2	6	18	9	19	21	12	1	.....	88	53
	Warm	.....	.....	.....	.....	.....	8	21	10	3	.....	.....	.....	42	41
1911	No thawing	3	11	3	2	0	0	0	0	0	0	4	4	27	.....
	Freezing	9	11	13	6	1	0	0	0	0	5	15	11	71	.....
	Cold	15	6	13	14	8	0	0	0	0	11	9	3	79	.....
	Cool	4	.....	2	8	10	5	4	6	5	8	2	.....	54	16
	Moderate	.....	.....	.....	.....	12	20	27	14	24	3	.....	.....	100	70
	Warm	.....	.....	.....	.....	.....	5	0	11	1	.....	.....	.....	17	16
1912	No thawing	8	11	9	1	2	0	0	0	4	3	2	13	53	.....
	Freezing	14	17	19	13	4	1	0	0	4	1	9	15	97	1
	Cold	9	1	3	13	6	2	0	0	3	12	14	3	66	2
	Cool	.....	.....	.....	3	11	11	3	3	10	14	5	.....	60	19
	Moderate	.....	.....	.....	.....	8	16	24	22	9	1	.....	.....	80	70
	Warm	.....	.....	.....	.....	.....	.....	4	6	.....	.....	.....	.....	10	10
1913	No thawing	14	14	8	3	0	0	0	0	1	4	2	16	62	.....
	Freezing	12	11	12	7	1	0	0	0	2	6	9	11	71	.....
	Cold	5	3	9	8	10	3	0	0	5	8	11	4	66	3
	Cool	.....	.....	2	12	11	8	4	0	10	13	8	.....	68	12
	Moderate	.....	.....	.....	.....	9	16	18	21	12	.....	.....	.....	76	65
	Warm	.....	.....	.....	.....	.....	3	9	10	.....	.....	.....	.....	22	22
1914	No thawing	[1] 5	.....	.....	6	2	0	0	0	0	0	2	.....	.....	.....
	Freezing	9	.....	.....	7	1	0	0	0	0	3	5	.....	.....	.....
	Cold	14	.....	.....	8	9	1	0	0	2	8	15	.....	.....	1
	Cool	3	.....	.....	9	11	3	1	0	5	16	8	.....	.....	5
	Moderate	.....	.....	.....	.....	8	22	25	22	21	4	.....	.....	102	76
	Warm	.....	.....	.....	.....	.....	4	5	9	2	.....	.....	.....	20	20
1915	No thawing	.....	.....	18	0	3	0	0	0	0	0	5	9	.....	.....
	Freezing	.....	.....	9	4	6	1	0	0	0	4	8	8	.....	1
	Cold	.....	.....	4	17	7	4	0	0	5	9	8	12	.....	4
	Cool	.....	.....	.....	9	10	10	7	9	8	13	9	2	.....	23
	Moderate	.....	.....	.....	.....	5	15	18	22	17	5	.....	.....	82	63
	Warm	.....	.....	.....	.....	.....	.....	6	.....	.....	.....	.....	.....	6	6
1916	No thawing	11	3	3	7	2	0	0	0	0	4	7	17	54	.....
	Freezing	13	14	9	4	2	0	0	0	1	3	10	8	64	.....
	Cold	3	12	5	11	6	2	0	0	3	9	8	6	65	2
	Cool	4	.....	14	8	12	9	1	5	9	10	5	.....	77	16
	Moderate	.....	.....	.....	.....	9	15	13	22	15	5	.....	.....	79	57
	Warm	.....	.....	.....	.....	.....	4	17	4	2	.....	.....	.....	27	27
1917	No thawing	11	11	12	5	5	0	0	0	0	1	2	5	52	.....
	Freezing	14	10	13	9	8	1	0	0	0	7	5	9	76	1
	Cold	6	6	5	9	11	2	0	0	1	7	15	13	75	2
	Cool	.....	1	1	7	5	8	0	6	11	10	8	4	61	15
	Moderate	.....	.....	.....	.....	2	13	18	21	18	6	.....	.....	78	61
	Warm	.....	.....	.....	.....	.....	6	13	4	.....	.....	.....	.....	23	23
1918	No thawing	19	6	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Freezing	6	11	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Cold	4	9	12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Cool	2	2	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Moderate	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Warm	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	No thawing	10.2	10.0	7.1	3.2	2.0	0.0	0.0	0.0	0.6	2.4	3.3	11.9	50.7	.....
	Freezing	10.9	11.9	11.0	6.6	3.2	0.4	0.0	0.0	0.9	3.7	8.6	10.7	67.9	.4
	Cold	7.9	6.0	8.2	12.1	7.8	1.8	0.0	0.1	2.5	8.5	11.1	7.6	73.6	1.9
	Cool	2.0	0.4	4.7	7.8	10.6	7.2	2.6	3.8	7.9	11.9	6.9	0.8	66.6	14.7
	Moderate	.....	.....	.....	0.3	7.4	16.9	19.0	20.4	17.1	4.5	0.1	.....	85.7	64.4
	Warm	.....	.....	.....	.....	.....	3.7	9.4	6.7	1.0	.....	.....	.....	20.8	20.6
														365.3	102.0

[1] January, 1914, based on record of Jan. 1-20 expanded.

It is seen that considerably more than half the days of the growing season have a moderate mean temperature, and that their number does not vary greatly from year to year. On the other hand, the number of warm days, practically all of which occur in the growing season, has varied in 8 years from 6 to 41 per year. Whether or not

such days are favorable to the growth of conifers, or whether, for the Rocky Mountain species, they may not represent excessive heat, might possibly be determined by growth studies; but nothing can be said on the subject at present.

No less interesting is the fact that January and March show not only a number of days with mean air temperatures above freezing, but the probability of a few days when the mean will be above 41°, the minimum scarcely below 32°, with the possibility of very effective thawing of the soil on well-insolated sites, and of some snow melting on any site at this elevation.

Ground temperature at control station.—The temperature of the atmosphere at the control station has been shown in considerable detail for the purpose of depicting prevailing conditions at a middle elevation in the mountains. In addition to this the temperatures at the control station are to serve as a base with which all other temperature records will be compared for their respective periods. At a number of the compared stations in various forest types only ground temperatures have been recorded, and at practically all these stations the elevation of the thermometers is considerably less than 20 feet. It is desirable, therefore, to know how the ground temperatures at the control station may compare with those of the higher aerial position.

As the control station is on a southerly exposure, though the gradient is very slight, it is to be expected that the purely local temperatures will be somewhat higher than the mean temperatures for the locality, recorded 20 feet above the ground. This proves to be true. In Table 6 are given, in condensed form, the results of a comparison of the two for two years ending March 31, 1918. In this period the maximum and minimum registering thermometers for the ground location were placed on a shielded board, which did not entirely protect them from reflected light and heat, but allowed very free cooling at night, as already described under "The Method of Study." As no thermograph was employed, the ground temperatures are not synchronous with those of the tower station, but they always represent periods about 8 hours later.

TABLE 6.—*Departure of ground temperatures from temperatures 20 feet above ground at the control station (with dissimilar exposure of instruments).*

Datum.	Record by months in degrees Fahrenheit.												Mean annual.	Mean growing season.
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
Mean temperature	+0.4	+0.5	+1.3	+2.3	+1.5	+0.9	+0.8	+1.1	+0.9	+1.5	−0.1	+1.1	+1.0	+0.9
Mean maxima	+1.7	+2.1	+3.0	+5.3	+4.5	+4.5	+4.1	+3.9	+4.2	+3.4	+2.2	+2.6	+3.5	+4.2
Mean minima	− .9	−1.2	− .4	− .7	−1.4	−2.6	−2.4	−1.7	−2.4	− .4	−2.3	− .5	−1.4	−2.3
Absolute minima	−1.8	−3.5	−1.8	−3.9	−1.2	−2.2	−2.8	−1.8	−1.0	− .7	−1.2	−2.1	−2.0	−2.2
Daily range	+2.3	+3.3	+3.4	+6.0	+5.8	+7.1	+6.5	+5.6	+6.6	+3.8	+4.5	+3.0	+4.9	+6.4

[1] See note, p. 29.

It is seen that the maxima are always higher and the minima always lower near the ground than at the 20-foot elevation. This results, of course, in a much greater daily range, and in a slightly higher mean temperature close to the ground. The difference seems to be greatest

in April and May, possibly because at that time the higher air is cooled by passing over snow fields, while locally the ground may be bare. The daily minima, it is found, are likely to show the greatest depression at the ground, in the coolest periods with extremely calm nights.

As has been indicated, the exposure of the thermometers at the ground was not such as to insure their recording strictly the temperature of the air itself at the time of the highest temperatures each day. Because this was realized, at the end of the period above described, the equipment, with thermograph added, was placed in a standard shelter, free from direct insolation or reflected insolation, and well ventilated through the floor to insure radiation at night. The site of the shelter was only a few feet from the other site, but was more fully clothed with vegetation. Since this change was made the higher maxima near the ground have been at all times just about counterbalanced by the lower minima, and the result has been, as before, a higher daily range for the ground position, but essentially the same mean temperature. The data for April, 1918, are especially interesting, because during this month, in the earlier arrangement, the greatest excess of ground heat was recorded. (See Table 7.)

TABLE 7.—*Departure of ground temperatures from temperatures 20 feet above ground at the control station (with similar exposure of instruments).*

	April, 1918.	July, 1918.
Mean temperature [1]	+0.2	+0.2
Mean maxima	+1.6	+2.2
Mean minima	−1.3	−1.9
Absolute minima	−1.8	−2.0
Mean daily range	+2.9	+4.1

[1] See note, p. 29.

Although these data are hardly extensive enough to invalidate those previously presented, it is probably safe to state that in an open situation of practically neutral aspect there is no important difference between the mean temperatures near the ground and those 20 feet above the surface; but that the ground location may easily show daily ranges exceeding by 3° or 4° those of the atmosphere above. Hence, of course, the probability of frost is much greater at the ground than on the tower where our main temperature record has been secured. It is seen from Table 4 that the probable minimum for the second decade of June, when expressed in terms of ground temperatures, may be as low as 32° F., and for the first decade of September as low as 34° F. It is thus apparent that the frost-free season may actually be 10 or 15 days shorter at the ground than would be indicated by Table 4; and of course it is the seedling at the ground level that is most sensitive to frost. On the morning of September 7, 1918, for example, the ground temperature was 30.2° F., and the frost was severe enough to kill tomatoes but not other garden vegetables. The minimum temperature 20 feet above ground was 32.5°.

These facts evidently do not apply to sites of decided northerly or southerly aspect, where the amount of insolation received may appreciably affect the local mean temperature. (Compare Stations 3A and 3G, 2A and 2G, in Table 9.)

Temperatures at various elevations in the Pikes Peak region.—The control station in this project, the Weather Bureau station at Colorado Springs, the Forest Service station at the Monument Nursery, the Weather Bureau cooperative station at Lake Moraine, and the special station at timber line, operated for 17 months, comprise an

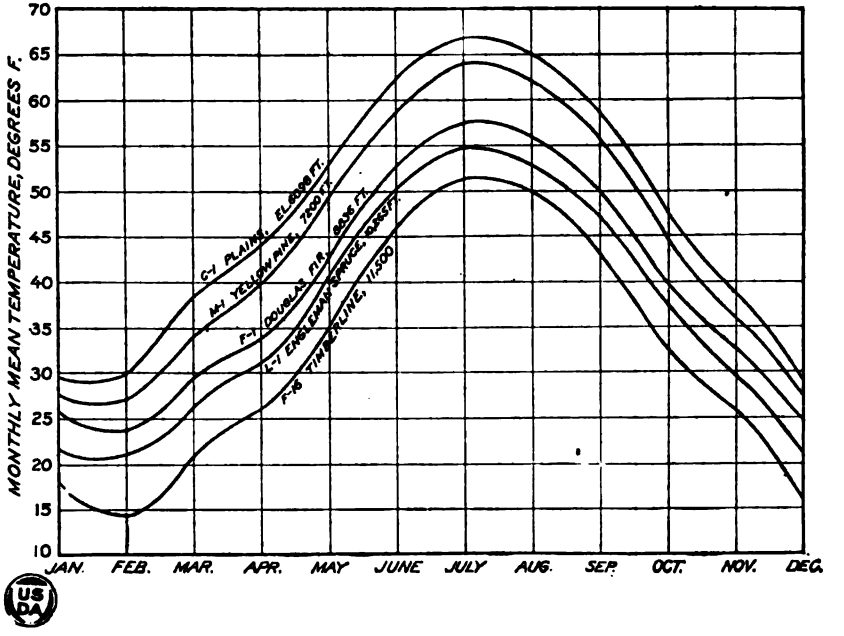

FIG. 2.—Monthly mean temperature for different elevations in the Pikes Peak region series.

altitudinal series (Table 8) from which a very definite idea may be obtained of the primary cause of forest zonation, if, indeed, temperature is a cause, as it appears to be.

In Table 8 the mean temperature of each of these stations, by months, is expressed by the difference between the temperature of the station in question and that of the control station, for the period indicated in column 4. The mean temperatures at the control station for the period up to April, 1921, are given in the center of the table, so that those for any other station may readily be computed to the same basis. In Figure 2 the absolute temperatures computed in this manner are shown.

TABLE 8.—*Comparative mean temperatures in Pikes Peak series.*

[Departures from control station temperatures during periods indicated and average temperatures for the control station.]

Station No.	Zone or type.	Elevation.	Period of record.	Record by months in degrees Fahrenheit.												Mean annual.[1]	Mean growing season.
				Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
		Feet.															
C–1	Plains	6,098	Jan., 1910, to Mar., 1918	+3.9	+6.1	+8.9	+10.1	+9.8	+9.4	+9.4	+9.2	+9.0	+7.9	+6.4	+4.4	+7.86	+9.28
M–1	Yellow pine type	7,200	Jan., 1911, to Mar., 1918[2]	+2.0	+3.0	+4.4	+6.2	+6.3	+5.9	+6.6	+6.2	+6.0	+5.1	+3.5	+2.9	+4.85	+6.21
F–1 control	Douglas fir zone	8,836	Jan., 1910, to Apr., 1921[3]	25.7	23.7	29.5	33.7	42.9	52.9	57.6	56.0	49.9	39.9	32.6	24.9	39.11	55.35
L–1	Spruce zone, limber pine type.	10,265	Jan., 1910, to Mar., 1918	−4.1	−2.8	−3.3	−2.0	−2.2	−2.6	−2.9	−3.3	−2.5	−2.1	−3.1	−3.5	−2.95	−2.91
F–16	Timber line	11,500	Oct., 1916, to Feb., 1918	−7.6	−9.3	−8.5	−7.8	−7.8	−7.0	−6.1	−6.0	−6.6	−7.6	−6.6	−8.8	−7.48	−6.39

[1] See note, page 29.
[2] Same omissions as control.
[3] With omissions.

For the stations below the control station the greatest excess of temperature is recorded in the spring and summer months and the least in winter; for the two stations at higher elevations the least deficiency is recorded in the summer months and the greatest in winter. This may be expressed more concretely. Although the control station is almost midway between the highest station and the lowest station in the series, its January temperature is 1.8° higher than the mean of the two and its July temperature is 1.6° lower. This is probably because of the high position of the thermometers at the control station, although it may have a broader significance than has been detected. Figure 3 shows the January gradient as a slightly convex curve, but the July gradient is not concave, the control station only being depressed.

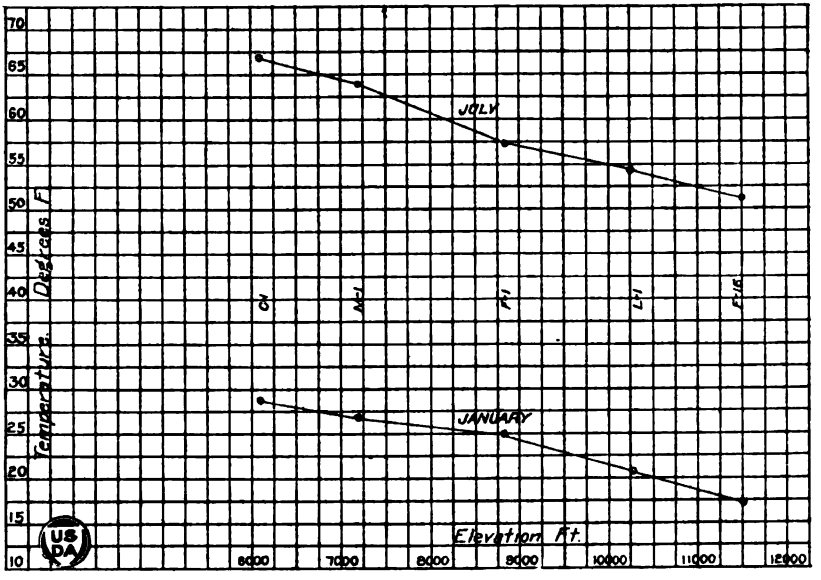

FIG. 3.—Temperature gradients in Pikes Peak region.

More important is the fact that the altitudinal temperature difference is least in the winter months, reaching a minimum of 11.5° in January and a maximum of 17.9° in April. The latter is plainly due to the quick disappearance of any snow that may fall at the lower elevations, while the high elevations suffer a handicap from the snow blanket, which is only nullified through the summer. The small difference in winter is probably due to the tendency of cold air to settle at lower levels, which sometimes results in an inversion of temperatures in the coldest weather.

The January gradient amounts to 2.1° per thousand feet elevation, the April gradient to 3.3°, and the mean for the year is 2.9°. It should not be considered that these figures have any general value, though they agree closely with the average of 10 Colorado watersheds as computed by Robbins (*20*).

TABLE 9.—*Comparative temperatures in different types at middle elevation, Pikes Peak region.*

[Departures from control station temperatures during periods indicated and average temperatures for the control station.]

Station No.	Type.	Elevation.	Aspect.	Height of thermometers.	Period of record.	Datum.	Records by months in degrees Fahrenheit.												Mean annual.[1]	Mean growing season.
							Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
		Feet.		*Feet.*																
F-1A..	Control.....	8,836	S.	20	Jan., 1910, to Apr., 1921.[2]	True mean temperature.	25.7	23.7	29.5	33.7	42.9	52.9	57.6	56.0	49.9	39.9	32.6	24.9	39.11	55.35
F-2A..	Yellow pine slope.	8,921	SW.	20	Mar., 1910, to Feb., 1912.	Comparative temperature.	+ .9	+2.0	+2.2	+1.9	+2.1	+2.0	+1.5	+2.0	+2.0	+2.5	+1.2	+1.7	+1.84	+1.80
F-2G..	.....do.....	8,921	SW.	1	Mar., 1915, to Feb., 1916.	.....do.....	+2.6	+4.3	+4.8	+4.7	+4.6	+4.8	+5.4	+4.2	+4.0	+4.6	+5.0	+3.9	+4.41	+4.81
F-12...	Yellow pine ridge.	9,164	[3] S.	1	Apr., 1915, to Mar., 1916.	.....do.....	− .4	.....	.....	+ .7	.....	.....	+2.9	.....	.....	+ .3	.....	.....	+ .87	.....
F-4....	Yellow pine slope.	9,117	E.	1	June to Sept., 1920.	.....do.....	.....	.....	.....	.....	.....	−1.1	−1.5	−1.3	−1.8	.....	.....	.....	.....	−1.30
F-6....	Limber pine slope.	9,060	NW.	1	Apr., 1915, to Mar., 1916.	.....do.....	+ .2	.....	.....	+3.2	.....	.....	+6.4	.....	.....	+1.4	.....	.....	+2.81	.....
F-13...	Limber pine high ridge.	10,300	Flat.	5	June, 1915, to Sept., 1916.	.....do.....	−2.0	−2.5	−3.4	−2.5	−2.2	− .3	− .7	−1.7	−1.6	−2.7	−2.7	−2.7	−2.10	− .96
F-7-8..	Douglas fir opening.	9,121	N.	1	Oct., 1915, to Dec., 1917.	.....do.....	−1.6	.....	.....	+1.4	.....	.....	+2.2	.....	.....	+ .3	.....	.....	+ .58	.....
F-14...	Douglas fir part cover.	9,087	N.	1	Apr., 1916 ,to Dec., 1917.	.....do.....	−2.2	.....	.....	+ .6	.....	.....	+2.1	.....	.....	0.0	.....	.....	+ .12	.....
F-15...	.....do.....	9,080	N.	1	Apr., 1916, to Dec., 1917.	.....do.....	−1.6	.....	.....	+ .8	.....	.....	+2.6	.....	.....	+ .1	.....	.....	+ .47	.....
F-9....	Douglas fir-spruce, virgin stand.	9,099	N.	1	Oct., 1915, to Dec., 1917.	.....do.....	−2.2	.....	.....	− .2	.....	.....	+2.4	.....	.....	− .9	.....	.....	− .22	.....
F-5....	Canyon spruce....	9,044	E.	1	June to Sept., 1920.	.....do.....	.....	.....	.....	.....	.....	−3.2	−5.1	−4.4	−5.6	.....	.....	.....	.....	−4.26
F-3A..	.....do.....	8,860	NE.	20	Mar., 1910, to Feb., 1912.	.....do.....	−1.1	+ .2	+ .2	+ .6	+ .7	−1.0	+ .3	+ .9	+ .2	− .6	− .8	−1.5	− .15	+ .08
F-3G..	.....do.....	8,860	NE.	1	Mar., 1915, to Feb., 1916.	.....do.....	−2.5	+3.0	+ .8	+ .1	+1.6	+2.4	+1.7	− .0	−1.2	−3.5	−1.0	−2.1	− .54	+1.08

[1] See note, page 29.
[2] With omissions.
[3] Nearly flat.

Other temperatures in the Pikes Peak Region.—The remaining temperature records for the Pikes Peak region (Table 9) are those obtained at the special stations in the vicinity of the control station, all but one at practically the same elevation, and designed to show the difference between types on slopes of different exposure. It is shown that a difference of exposure may create as great a difference in local air temperature as a difference of 1,000 or 2,000 feet in elevation; hence, so far as air temperatures determine, almost any species may find the proper conditions for initiation at a middle elevation.

In Table 9 the same plan has been followed as in Table 8, the records being for a variety of periods and none covering the whole period during which the control station has been operated. Several of the records do not have sufficient individual value to warrant the computation of means for every month. In these records one month in each quarter has been considered, and the annual means have been derived from these four months, a comparison being made, of course, with the same months at the control station.

It is seen from Table 9 that the growing season excesses of the outlying stations are somewhat greater than the excesses for the whole year, where both have been computed, except at Station F–2A, which, like the control station, represents conditions 20 feet above the ground. These facts may account for the low summer temperatures of the control station, as compared with other stations in the Pikes Peak series.

When the most typical pine and spruce stations shown in Table 9 are compared with corresponding types at different elevations, as shown in Table 8, namely, F–2 with M–1, and F–3 with L–1, it is found that the air temperatures of corresponding forest types vary in the same direction, but that the local variations are not so great as those in which a difference in elevation is involved. The pine type locally may be 4.4° warmer than the control station, if the ground conditions for the whole year are considered, but at a lower elevation the pine type is 4.8° warmer. Here the agreement is close.

One of the local spruce types is decidedly cooler than the control station for the summer period in which record has been secured, but the other is cooler only during the winter. In the first spruce type there is a very marked depression of the minima, undoubtedly due to cold air drainage; but in the second type the summer maxima are so high as to lead to the belief that the poorly sheltered thermometers received some direct insolation, the possibility of which was not suspected during the observations. It is to be noted that insolation, reaching the ground through breaks in a heavy canopy, produces very sharp effects on account of the stagnation of the air. Because of the factors possibly affecting the record for F–3, more significance should be attached to the soil temperatures, which more clearly show the general coolness of this site.

It is noted that the western yellow pine ridge (F–12), like the control station, is freely exposed to wind and is practically no warmer than the control station. It will also be remembered that this site is reproducing to Douglas fir and limber pine, as well as to yellow pine, and that the yellow pine is in a very unhealthy condition. This condition is equally well brought out by the soil temperatures. In the summer, at least, lower air temperatures occur at F–4, where the maxima are not high on account of the easterly exposure, and

where the minima are relatively low after the long period of radiation, and possibly somewhat affected by air drainage in the slight depression.

The temperature record of the local limber pine type (F–6) is a wholly dependable one, and is, perhaps, significant of the requirements of this species. It is especially noteworthy that the winter temperatures, in spite of the fact that they represent ground conditions, are slightly higher than those of the control station, and there can be little doubt that this is due to direct exposure to west winds. As the slope is a northwest one, the high summer temperatures may be accounted for only by the fact that such insolation as is received locally, coming late in the day when the general air temperatures are already high, causes high and late maxima and hence high minima.

The record of the higher limber pine type (F–13) does not seem to bear out the assumption that this species demands a great deal of heat. Although the mean temperatures are always considerably lower than for the control station, it is, however, possible to conceive that during the summer months, when the difference is rather slight, this site experiences a few hours of high temperatures satisfactory to a heat-demanding tree, and that the growth of limber pine is restricted to such short periods. Even so, the maxima are considerably lower than for the control station, especially during the winter months. The maxima for the growing season are 1.7° lower than at the control station, the minima 1.8° higher, and the mean daily ranges 3.5° less. For this period the station would compare favorably with ground temperatures at the control station. The daily ranges at the higher station are relatively the least during the winter months. The decade minima are usually higher during the coldest months when they are most affected by wind. For the growing season they are 0.8° lower, on the average, and only very rarely higher than at the control station.

On the whole, no plausible explanation is found for the occurrence of limber pine in burns of the spruce zone except on the assumption that ground temperatures during the growing season may be about the same as at lower elevations, at least giving short periods of favorable temperature. Having no competition, the limber pine is able to survive even with a very small annual accretion.

The temperatures of the four north-slope stations that represent different weights of cover in the Douglas fir type, are worthy of note. The mean temperature in the fully open position is slightly in excess of that of the control station—about as much in excess as the ground temperatures at the control station might be expected to be. The two stations under partial cover are almost identical with the control station for the year as a whole; however, they are decidedly cooler in winter and warmer in summer. These high temperatures on a north slope are to be accounted for only by air stagnation, the wind movement being much less here than at the control station, even if velocities at the latter point are reduced to ground conditions. The whole-cover station (F–9) is appreciably cooler than the others during most of the year.

The mean temperatures, however, do not tell the story for these four stations. In Table 10 the extremes and daily ranges for the control station and the four north-slope stations are shown. The absolute figures given for the control station are for the longer period corresponding to Station 7–8, namely, October, 1915, to December, 1917.

For the most part, the variations from the control station, whatever the condition measured, progress rather regularly through the four stations, that is, become greater or smaller, as the case may be, with increase in density of the cover. The influence of cover may then be directly measured by comparing Station 9 with 7–8. In July, the complete canopy reduces the maxima 2.2° and raises the minima 2.5°; in January the effect on the minima is similar, but, as almost no January sunlight reaches the ground under the canopy, the maxima also are reduced about 3.1°.

TABLE 10.—*Actual temperatures at the control station and departures therefrom on north-slope Douglas fir sites, with different weights of cover.*

Station.	Datum.	Record in degrees Fahrenheit.				Mean annual.[1]
		January.	April.	July.	October.	
Control, Oct., 1915, to Dec., 1917.	Mean maximum	33.86	42.84	70.14	52.67	49.88
	Mean minimum	11.46	22.09	47.52	28.15	27.30
	Daily range	22.40	20.76	22.62	24.51	22.57
	Absolute minimum	−15.65	4.70	41.0	5.80	8.96
F–7–8, open	Mean maximum	− 1.9	+2.8	+6.3	+1.5	+2.2
	Mean minimum	− 1.4	0	−1.8	−1.0	−1.0
	Daily range	− .5	+2.8	+8.1	+2.5	+3.2
	Absolute minimum	− 1.0	−3.4	−1.3	−1.7	−1.9
F–14, part cover	Mean maximum	− 4.0	+ .5	+5.0	− .1	+ .3
	Mean minimum	− .3	+ .7	− .6	+ .2	0
	Daily range	− 3.7	− .2	+5.6	− .2	+ .4
	Absolute minimum	− .2	+1.2	− .6	−1.0	− .1
F–15, part cover	Mean maximum	− 3.8	+ .1	+4.9	−1.0	0
	Mean minimum	+ .6	+1.5	+ .2	+1.2	+ .9
	Daily range	− 4.4	−1.4	+4.7	−2.2	− .8
	Absolute minimum	+ .2	+2.4	− .2	0	+ .6
F–9, virgin stand	Mean maximum	− 5.0	−1.1	+4.1	−3.3	−1.4
	Mean minimum	+ .7	+ .7	+ .7	+1.5	+ .9
	Daily range	− 5.7	−1.8	+3.3	−4.8	−2.2
	Absolute minimum	+ 3.4	+ .4	− .2	+1.0	+1.2

[1] See note, p. 29.

October is doubtless the most important month with respect to the fate of new, poorly developed seedlings. Its temperatures are similar to those of September, when the first frosts are to be expected. In October the complete canopy has the effect of raising the mean minima 2.5° and the absolute minima 2.7°. This is sufficient to postpone freezing under the canopy for several days, the mean rate of cooling, figuring from September to October, being 1° every 3 days. Frost may, then, "normally" be postponed a week through the protection of the canopy. This should be of some slight benefit to seedlings. However, it should tend to favor the less hardy species, Douglas fir, as against the species, Engelmann spruce, which in many of its habitats is subject to frost every month in the year. This it does not do. The canopy tends to favor spruce, but fir and limber pine flourish more abundantly in the open. It may, therefore, be conceived that the influence of the canopy in reducing extremely high temperatures, or mean temperatures for the year as a whole, has more importance in selecting the successful species.

Other air temperatures at more distant points.—The mean air temperatures for a number of stations in the central Rocky Mountain region, believed to be representative of its different localities are shown on a comparative basis in Table 11. With a few exceptions the records of these stations cover the period during which the control station has been operated, up to March, 1918, and all the comparisons are made between identical months of the eight years, or parts thereof.

TABLE 11.—*Average mean temperatures for the control station and departures therefrom for scattered stations in the central Rocky Mountain region.*

[Actual mean temperatures given for the control station.]

Station No.	Type.	Period.	Comparative temperatures in degrees Fahrenheit.												Year.[1]	Growing season.
			Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
F-1	Control station	Jan., 1910, to Apr., 1921 [2]	25.7	23.7	29.5	33.7	42.9	52.9	57.6	56.0	49.9	39.9	32.6	24.9	39.11	55.35
H-2	Nebraska sandhills	May, 1919, to Apr., 1921	− 1.2	+ 3.5	+ 8.4	+12.8	+12.3	+15.5	+16.3	+14.5	+13.7	+ 9.1	− .1	− 4.7	+ 8.36	+15.46
P-1	Southern Colorado western yellow pine	Jan., 1910, to Dec., 1916 (2) [3]	− 7.4	+ .1	+ 2.7	+ 6.7	+ 5.8	+ 4.4	+ 6.4	+ 5.7	+ 6.0	+ 3.6	+ 1.3	− 4.2	+ 2.58	+ 5.53
D-1	Black Hills western yellow pine	1910 to 1918, except 1915 (12)	− 4.8	− .2	+ 3.0	+ 7.4	+ 7.2	+ 8.2	+10.1	+ 7.1	+ 6.2	+ 3.8	+ 2.5	+ .9	+ 4.28	+ 8.25
F-17	Northern Colorado Douglas fir (east)	1910 to 1918	− 4.1	− .4	0	+ 1.8	+ 1.5	+ 1.9	+ 2.3	+ 2.6	+ 1.3	+ .2	− .4	− 1.0	+ .47	+ 2.15
W-A1	Southern Colorado Douglas fir (north)	Nov., 1910, to Dec., 1917	− 9.1	− 4.2	− 3.0	− .9	− .4	− .5	− 1.0	− 1.7	− 2.1	− 2.8	− 6.4	− 8.0	− 3.35	− 1.17
F-18	Fraser River lodgepole pine	1910 to 1918 (1)	−13.9	− 9.9	− 7.8	− 4.2	− 5.1	− 4.9	− 4.8	− 5.2	− 5.5	− 6.1	−10.0	−13.0	− 7.56	− 5.05
N-1	Western slope lodgepole pine	1910 to 1918	− 8.7	− 5.2	− 3.6	− .2	+ 1.2	− .5	− .5	− .6	− .9	− 1.4	− 4.9	− 7.6	− 2.74	− .56
F-11	Southern Wyoming lodgepole pine	Mar., 1911, to Mar., 1918 (12)	− 9.5	− 7.1	− 7.4	− 4.7	− 5.4	− 5.8	− 5.1	− 5.0	− 6.4	− 5.7	− 6.5	−10.8	− 6.62	− 5.41
L-2	Continental Divide lodgepole pine	1910 to 1918	− 9.4	− 5.2	− 5.4	− 3.2	− 2.8	− 3.3	− 2.8	− 2.9	− 3.0	− 4.3	− 6.5	− 7.6	− 4.68	− 2.98
W-G	Southern Colorado high spruce	Oct., 1913, to Dec., 1917	−10.2	− 7.3	− 7.3	− 6.4	− 7.2	− 5.8	− 6.1	− 5.2	− 7.0	− 6.1	− 6.7	− 8.5	− 6.98	− 5.84

[1] See footnote (6), p. 29.
[2] With exceptions already noted under description of this station. Comparisons are made on basis of period up to March, 1918, except for Station H-2.
[3] Number in parentheses indicates number of months missing in inclusive period, in addition to omissions for control station.

The observations at all outlying stations, it is believed, have been made at an elevation of about 5 feet above the ground as compared with 20 feet for the control station, but, as has been shown, this factor can not materially affect the mean temperature for any month. An examination of such data as are readily available on the daily range of air temperatures for other localities shows that a range of about 20° to 22° is characteristic throughout the region under discussion, except in the Nebraska sandhills. The relation of maxima and minima to means will be, therefore, almost the same as the relation at the control station.

Air temperatures compared by forest types.—1. The yellow pine station in southern Colorado shows less excess over the control station than does a station 400 feet distant, and less than the Monument station at the foot of the Pikes Peak series, if the comparison is made for the whole year. For the growing season, however, the southern Colorado station is slightly warmer than the local yellow pine type, but not equal to the Monument station. In both southern Colorado and the Black Hills yellow pine endures much lower winter temperatures than occur at any but the highest elevations in the Pikes Peak region. The fact must not be lost sight of, however, that these low temperatures are endured in the presence of a deep blanket of snow which may largely prevent soil freezing.

All of the data for the western yellow pine sites may be briefly summarized and reduced to absolute temperatures, in the order of growing-season temperatures, as follows:

	Growing season.	Year.	Locality.
	°F.	°F.	
Highest	63.60	43.39	Black Hills.
	61.56	43.96	Pikes Peak, M-1.
	60.88	41.69	Southern Colorado.
	[1] 58.65	42.23	Fremont, south slope.
	[2] 56.65	39.98	Fremont, ridge.
Lowest	54.05	.....	Fremont, east slope.
Total range	9.55	3.98	

[1] Averaging ground and air conditions.
[2] Based on May, July, and October differences.

It is then seen that the Black Hills station, in a low-lying region where other forest species are practically excluded, has the highest growing-season temperatures of any of the western yellow pine types, and with this condition and fairly high rainfall the species reaches its optimum development, at least in reproduction. Where the lowest growing-season temperatures of yellow pine types are found Douglas fir and limber pine also appear in considerable proportions.

Establishment of yellow pine by planting has been successfully accomplished in the Nebraska sandhills, where the mean temperature for the growing season is in excess of 70°, and for the year is nearly 48°. The former is about 7° in excess of the Black Hills yellow pine type. These conditions, however, not only have prohibited natural extension of pine to this region, but have caused considerable losses in plantations; furthermore, they have precluded direct seeding. Although, of course, all the conditions which accompany these temperatures must be referred to, still the more this matter is studied, the greater is the conviction that temperatures do very largely control the distribution of species, although the air temperatures as measured

may fall far short of showing the really critical conditions which must ultimately be examined. In considering these Nebraska temperatures, the effects of a scantily covered and strongly mineral soil are apparent in the high daily ranges, which in clear weather often go to 40° and occasionally to 50°, while averaging 27.6° for the year and 30.4° for the growing season. Thus, for the growing season the mean maxima are 20.7° in excess of those at the control station, while the minima are only 11° in excess, the difference becoming less in late summer. These facts, considered with those of distribution, are at least strongly suggestive that, although yellow pine may make vigorous growth with temperatures which are both theoretically and actually very favorable for corn, yet the seedlings at their most sensitive stage must have much more moderate conditions. The relation of these high temperatures to surface drought in such a sandy soil must not be overlooked, especially when it is noted that seeding fails even in well-shaded situations.

2. The northern Colorado Douglas fir site (F–17) should possess characteristics somewhat similar to those of the control station, as it is similarly situated on the east slope of the mountain range. Its considerably lower winter temperatures, however, indicate that it is not so potently affected by descending winds, and that these may be peculiarly developed in the Pikes Peak region. On the other hand, the southern Colorado station (W–A1) is very much colder than the control station during the winter—the locality being peculiarly free of wind at all times—and appreciably cooler also throughout the growing season, although the latter difference is not a serious one.

If the north slope open and covered stations are used to represent Douglas fir in the Fremont locality, the temperatures for this type, as computed, may be summarized in the following order based on the growing season:

	Growing season.	Year.	Locality.
	°F.	°F.	
Highest	57.50	39.58	Northern Colorado.
	[1] 56.65	39.59	Fremont, cut-over.
	[1] 55.78	38.89	Fremont, closed stand.
Lowest	54.18	35.76	Wagon Wheel Gap, north.
Total range	3.32	3.82	

[1] Based on April, July, and October differences.

The Douglas fir temperatures, which happen to have been taken entirely at middle elevations, do not show so great a range as those of the yellow pine type. In either annual or growing-season requirements, the species seems to have a somewhat limited range, giving way appreciably to spruce under the lowest temperatures here recorded. Even if the brief record for the south-slope station at Wagon Wheel Gap (W–2A) be considered, temperatures in excess of those noted are not found. The south slope here shows an excess of about 1.8° over the corresponding north-slope site, and the conditions thus produced seem to be about the maximum that fir will bear, if the large summer mortality among seedlings may be taken as evidence. Further evidence of the lack of adaptive qualities in fir is found in the fact that in the Pikes Peak region, as observed by the writer, Douglas fir does not go to such high elevations as the western yellow pine occasionally does.

3. The lodgepole-pine type, wherever found, seems to be characterized by very low winter temperatures and also by growing-season temperatures considerably lower than those of the control station. It is believed that the low winter temperatures of this type are always accompanied by heavy snowfall, which, at least at the southern Wyoming station, arrives so early as to prevent deep soil freezing. These facts suggest that the most obvious requirement for reproduction of lodgepole pine is a winter climate of such low temperatures and with such an abundance of snow that the evaporation factor is essentially nullified. This would seem to explain the absence of lodgepole pine from the Pikes Peak region, but not its ability to grow there when planted. As has been shown by the physiological studies, it is more probable that in the Rocky Mountains it is crowded out of its normal temperature zone by demands for moisture which can be met only at elevations where the snowfall is heavy and well conserved throughout the winter. The mean temperatures indicated by these data are:

	Growing season.	Year.	Locality.
	° F.	° F.	
Highest	54.79	36.37	Western slope.
	52.37	34.43	Continental Divide.
	50.30	31.55	Fraser Basin.
Lowest	49.94	32.49	Southern Wyoming.
Total range	4.85	4.82	

It will be noted that these maxima overlap somewhat into the zone of Douglas fir temperatures. It will also be noted later that the temperatures enjoyed by lodgepole pine come within the range of temperatures enjoyed by spruce.

4. The single spruce station listed in this table (W–G) shows a January temperature scarcely lower than the Douglas fir station (W–A1) of the same region, but for the remainder of the year the high spruce type is much cooler. The annual and growing-season means of this station are also remarkably close to those of the timberline station (F–16, Table 8) of the Pikes Peak region, the two being at almost the same elevation, and the former not more than 500 feet below timber line for its locality. This suggests that an annual mean of slightly less than 32° F. may be the limiting factor for all forest growth in the central Rockies. It is suspected, however, that such a limitation is placed upon growth only indirectly if at all.

All of the spruce temperatures may be summarized as follows:

	Growing season.	Year.	Locality.
	° F.	° F.	
Highest	[1] 55.93	[1] 38.77	Fremont, canyon type.
	52.44	36.16	Fremont, middle zone.
	51.09	.....	Fremont, canyon type.
	49.53	32.13	Wagon Wheel Gap, near timber line.
Lowest	48.96	31.63	Fremont, timber line.
Total range	6.97	7.14	

[1] Average of ground and air conditions at F–3.

Summary of mean air temperatures.—To bring all the preceding data together for closer study, the average temperature of each type, as studied, and the differences within each type, may be shown as follows:

Type.	Number of stations.	Mean temperatures.			
		Growing season.		Year.	
		Range.	Average.[1]	Range.	Average.[1]
		°F.	°F.	°F.	°F.
Plains	1	.....	64.6	.....	47.0
Sand hills	1	.....	70.8	.....	47.5
Western yellow pine	6	9.6	59.2	4.0	42.2
Limber pine	3	6.6	55.2	5.8	38.4
Douglas fir	4	3.3	56.0	3.8	38.5
Lodgepole pine	4	4.8	51.8	4.8	33.7
Engelmann spruce	5	7.0	51.6	7.3	34.7

[1] Of stations listed in four tables just preceding.

CONCLUSIONS REGARDING AIR TEMPERATURES.

As has already been pointed out, from the physiological standpoint the air temperatures per se may mean very little. It has been made apparent by the preceding studies that the several species here considered show wide differences in photosynthetic capacity, and it is logical to assume that the species which makes the most effective use of sunlight will succeed best in a cool environment. On this basis alone the upward extension of any species would be plainly limited by competition with another species of greater shade tolerance and correspondingly low heat requirements for effective growth. In this consideration it seems that the mean air temperatures for the growing season serve as well as any other criteria to explain both the altitudinal zonation of the mountain forests and the sharp contrasts in cover as between opposing slopes. In fact, as regards mean air temperatures, it has been shown that the same differences may be produced locally as well by change of aspect as by great differences in altitude.

But even if the zones and aspect types are accepted as temperature types primarily, and as sufficiently well described and limited by the growing-season means, an explanation has not been provided, in agreement with physiological theory, for the fact that each species has a lower altitudinal limit and an apparent maximum-temperature limit. The mean air temperatures can of course give only a suggestion of what such limits might be, and even the maximum air temperatures, it is believed, would fall so far short of depicting the really critical conditions that it does not seem worth while to tabulate them for this purpose. When one considers all the facts of forest distribution, together with such phenomena as the marked success of yellow-pine planting in the Nebraska sand hills and the vigorous growth of the species there, the conclusion is unavoidable that the only conditions worth studying, in the attempt to explain the natural limitations of the forest types, are those which have the most acute bearing on seedlings in the infant stage. Even the matter of germination may confidently be put aside, for year after year great numbers of seedlings are germinated, but few of them survive even to the end of the first growing season.

To understand the limitations of the forest types, therefore, it seems essential that there should be knowledge of the maximum temperatures to which seedlings are subjected, and by this is meant the maxima at the surface of the soil, where injury to seedlings is first apparent. These will not wholly tell the story, as the fatal effects are probably produced by lack of moisture; but the maximum temperatures would probably be a very fair criterion as to the degree of drought produced if some allowance were made for the type of soil.

Considering the matter in its broader aspects, it is fairly apparent, even before the other conditions of the forest types have been considered, that temperatures are primarily and closely controlling in the natural distribution of each species. It is to be expected that each would show some range of requirements, and that, as indicated by the data, spruce and yellow pine might show a somewhat greater range than the other species, because, occupying the edges of the stands, they are not so closely limited by competition. It may be, of course, purely accidental that the data do show this quality. And in considering the range of temperatures under which any species thrives it should be apparent that different temperatures, as they are measured, may be physiologically alike. Thus, it may be said, atmospheric humidity modifies the apparent temperatures for plants as it does for animals. The plant temperature must be relatively higher in a moist than in a dry atmosphere. On the contrary, in the critical connection mentioned as affecting seedlings, the greater the humidity, no doubt, the higher the temperature that may be tolerated.

These considerations explain fully enough why the absolute temperatures enjoyed may cover a wide range, and especially why the temperature requirements in different regions may be markedly different. In this connection, however, it should be remembered that different races of the same species are now being dealt with. The behavior of the Montana and Arizona forms of yellow pine has been briefly described in the earlier physiological paper. The functioning of the Arizona form would lead one to expect that it would tolerate higher temperatures than the Colorado variety. Pearson (*19*) shows that the mean temperatures of the type in Arizona during the growing season—June to September—range from 59.5° to 65.6° F., the highest (Williams) being a little in excess of the Black Hills temperature, and being accompanied by a daily range of 33°, and with less precipitation than is characteristic of the Black Hills. The Arizona forest, however, reproduces itself with the greatest difficulty, while in the Black Hills reproduction is very abundant.

The temperatures given by Larsen (*13*) for an even longer growing season—May to September—are 61.2° for the Washington-Idaho section, 59.8° for the intermontane region of Idaho and Montana, and 64.7° for eastern Montana. It is believed that the intermontane region with the lowest temperature is the most favorable as regards moisture. The relatively high value for the type in eastern Montana may be determined by summer dryness, but there is a possibility, at least, that the Chinook of that region may have some influence in confining the type to warm sites where the danger of soil freezing is least.

Pearson's (*19*) Douglas fir type in the San Francisco Mountains, at an elevation of 8,900 feet, has a growing-season temperature almost identical with the average, but the annual mean is about 3° higher than the average in Colorado.

There are, then, no surprising differences even when widely separated types are compared. It seems evident that the temperature requirements of the three principal forest trees of the region—yellow pine, Douglas fir, and spruce—are in accord with their physiological properties, but that lodgepole pine, which theoretically would grow much better in conditions similar to those enjoyed by yellow pine, is compelled to take a much cooler site because of its inability as a seedling to cope with drought. Its ability to tolerate the extreme heat of fresh burns and to thrive here where competition has been destroyed is entirely in keeping with its physiological properties, and the inability to reproduce in its own shade is further evidence that the low temperatures are merely tolerated, not enjoyed.

Somewhat similarly, limber pine, although sometimes extending almost to timber line, is plainly a tree of the open. Its occupation of the wind-swept northwest slope, the warmest site here studied, may be temporary, but it is believed to result from a greater resistance to wind drying than is possessed by species which function more vigorously. Thus it seems safe to say that none of the species chooses warmer sites than, relatively speaking, its physiological conditions dictate, and that, when driven by other considerations to sites relatively too cool, the tenancy is only temporary.

WIND, HUMIDITY, AND EVAPORATION.

It would appear logical to follow the discussion of air temperatures by that of soil temperatures, for the two must be somewhat closely related, and their consideration in direct sequence would facilitate fixing in mind the temperature conditions, as a whole, for various kinds of sites. There is, however, one very potent reason for postponing the consideration of soil temperatures until all of the atmospheric conditions have been carefully weighed. This is the fact that the soil-temperature data which we are enabled to present here are not, perhaps, so important as temperatures as they are for expressing the physical status of the soil and the availability of its moisture. How important it is that the soil should be frozen one or six months is, obviously, not to be determined until we have first considered the atmospheric conditions and measured, in a rough way, the demand to give up moisture by transpiration which may be made upon trees during the period of soil freezing. It is therefore desirable and in fact necessary to proceed with the consideration of atmospheric conditions before taking up the subject of soil factors.

WIND MOVEMENT.

Wind movement at the control station.—The topographic position of the control station has already been described in general. The station lies in a fairly wide valley formed by the junction of three stream channels. It is not in the bottom of the valley, but on a low ridge lying between two of the streams. As the anemometer is placed on a tower 20 feet above the ground, the air movement is not strictly that of the valley bottom, but represents a slight gradation toward the freer movement of the higher air strata. Nevertheless, the elevation of the anemometer, 50 feet or less above the lowest adjacent ground in the valley, is inconsiderable in comparison with the elevation of the walls of the valley. At this point these rise some 300 feet higher on the north, at an angle of 18 degrees, and about

200 feet higher on the south, at an angle slightly less. Toward the head of the more open of the three stream channels, in a northwesterly direction, the elevation is somewhat less than 200 feet, and the angle is 7 degrees. Down the valley the immediate negative elevation is still less.

The control station is thus appreciably affected only by air currents paralleling the main axis of the valley, namely those from the southeast or the northwest. Only rarely do currents from the southwest or south reach the station through the valley having its origin in that direction, as the station is somewhat west of the axis of that valley. Due to this influence of local topography there is every reason to believe that the full velocity of the prevailing winds is not recorded. The prevailing wind direction is always southeast during the periods when valley breezes constitute the chief element of air circulation, that is, during the summer; and always northwest or west, the former predominating, when mountain breezes or anticyclonic winds dominate the atmosphere. Cyclonic winds, which are usually of northeasterly origin, are rarely recorded as such at this station, and may appear as east or southeasterly winds. It must, therefore, be recognized that winds from the northeast or north, and to a less extent those from the south and southwest, must conform to the configuration of the valley to become effective at this station.

Further evidence of local influences is given in the gusty character of winds, whenever the velocity is at all high. This is not shown by records, since the gusts of wind are usually so short that any individual mile recorded may be made up of several squalls and intermediate calms. From extended observation the writer has estimated that the momentary velocity of the wind gusts is fully twice the rate of movement indicated by the anemometer records. In any study of the mechanical effects of wind this discrepancy would be very important, and only the pressure-tube anemometer or some similar contrivance could possibly depict the actual conditions. For the purposes of this study, on the other hand, momentary velocities are of no importance, and, it may as well be stated at this point, the mechanical effects of wind in the region under study are quite negligible. The soil is of such firm texture and the trees are so short-boled as to preclude windfalls—except, of course, when trees have become badly decayed—and even the breaking of limbs is extremely rare. On one occasion in eight years, at a time when intense cold was accompanied by high wind, considerable snapping of twigs was noted. Even this was confined to the especially long side branches whose rapid, slender development subjected them to unusual exposure.

At timberline, of course, the mechanical effects of wind are always apparent in the distortion of limbs and the one-sided development of trees as a whole. At lower elevations that which appears to be a similar mechanical distortion of form has been traced by the writer (*6*) to winter-killing of limbs on the most exposed portions of the trees.

With these facts in mind, the recorded wind movements at the control station, as shown in Table 12, may be considered. As this record is an almost perfect one, it can be quite positively stated that apparent discrepancies between succeeding decades or corresponding periods of different years are true to the facts. The credit belongs to the designer of the thoroughly practical Robinson anemometer, and to the fact that the daily dial readings are compared with an almost unbroken automatic record.

TABLE 12.—*Total wind movement at the control station, beginning and ending at 8 a. m.*

Year.	Decade.	Record in miles per decade and month.												Total annual.	Total growing season.
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
1910	1	.....	1,090	1,273	1,265	1,216	1,386	1,188	1,058	1,240	1,081	1,155	1,918	.....	.....
	2	.....	1,811	1,032	1,261	1,143	1,328	1,162	965	996	1,168	828	848	.....	.....
	3	.....	1,589	1,775	1,151	1,234	1,231	1,202	1,174	968	1,187	1,853	1,334	.....	.....
	Month[1]	.....	4,489	4,080	3,677	3,592	3,945	3,552	3,197	3,203	3,436	3,836	4,100	[2] 46,508	11,933
1911	1	2,038	1,816	2,270	1,580	1,359	1,365	940	1,130	1,087	1,078	1,515	894	.....	.....
	2	2,349	1,085	1,009	1,397	1,445	1,110	852	1,051	1,155	1,206	2,169	645	.....	.....
	3	1,961	822	1,760	982	1,543	1,154	1,115	1,090	948	881	1,173	1,544	.....	.....
	Month.	6,348	3,722	5,039	3,958	4,346	3,629	2,907	3,272	3,190	3,165	4,858	3,084	47,518	10,895
1912	1	2,682	1,183	1,171	1,417	1,434	1,133	1,253	982	1,223	1,325	1,079	982	.....	.....
	2	1,474	1,578	1,710	1,750	986	942	1,047	893	928	1,111	1,013	1,470	.....	.....
	3	1,328	946	1,151	1,375	1,790	1,168	1,032	1,148	877	1,334	1,254	1,807	.....	.....
	Month.	5,484	3,707	4,033	4,543	4,210	3,242	3,332	3,022	3,028	3,770	3,347	4,259	45,977	10,820
1913	1	1,862	1,111	1,168	1,325	1,112	1,147	1,226	1,192	956	1,311	1,073	1,052	.....	.....
	2	2,949	907	1,523	1,088	1,203	1,172	1,117	924	978	965	926	916	.....	.....
	3	1,329	982	1,766	1,179	1,343	1,140	1,109	1,018	872	1,185	873	1,219	.....	.....
	Month.	6,140	3,000	4,458	3,592	3,658	3,460	3,453	3,134	2,806	3,461	2,872	3,187	43,220	11,003
1914	1	1,543	.....	.....	827	1,209	1,447	908	947	1,004	1,201	854	768	.....	.....
	2	2,017	.....	.....	1,151	877	1,061	945	1,023	1,360	1,025	1,000	.....	.....	.....
	3	.....	.....	.....	1,280	1,366	1,222	985	1,207	1,131	1,141	873	.....	.....	.....
	Month.	.....	.....	.....	3,258	3,452	3,730	2,838	3,177	3,495	3,366	2,727	.....	.....	10,749
1915	1	.....	.....	831	1,252	1,267	1,084	1,202	946	1,006	1,131	1,310	834	.....	.....
	2	.....	.....	1,149	998	1,213	1,557	1,137	886	1,231	962	1,708	1,925	.....	.....
	3	.....	.....	1,194	1,136	1,236	1,096	1,043	1,036	1,188	1,168	1,788	2,128	.....	.....
	Month.	.....	.....	3,173	3,386	3,715	3,737	3,382	2,868	3,425	3,261	4,805	4,888	.....	10,993
1916	1	2,388	1,571	2,622	1,145	1,464	1,244	1,350	1,032	1,173	1,410	1,324	1,594	.....	.....
	2	1,387	932	1,530	1,483	1,191	1,173	1,015	955	1,046	1,299	914	2,166	.....	.....
	3	1,524	1,058	1,588	1,053	1,940	1,281	1,068	1,010	1,144	1,196	1,222	1,916	.....	.....
	Month.	5,299	3,561	5,740	3,681	4,595	3,699	3,433	2,997	3,364	3,906	3,459	5,676	49,410	11,302

1917	1	1,570	1,404	1,574	1,293	970	1,358	1,115	1,166	917	1,092	960	1,824	.....	.....
	2	1,389	1,467	1,478	1,328	1,166	1,163	1,076	915	896	1,443	1,059	1,588	.....	.....
	3	2,328	1,881	2,130	1,006	1,132	1,314	1,266	1,059	1,045	1,943	1,207	1,369	.....	.....
	Month.	5,288	4,752	5,181	3,627	3,269	3,835	3,456	3,140	2,858	4,478	3,226	4,781	47,892	11,349
1918	1	1,153	1,740	1,970	1,146	1,464	1,124	953	1,026	942	.....	.....	.....	.....	.....
	2	1,243	1,891	1,665	1,241	1,312	1,199	944	924	985	.....	.....	.....	.....	.....
	3	1,616	1,785	1,341	1,173	1,765	1,180	1,090	1,251	.....	.....	.....	.....	.....	.....
	Month.	4,012	5,416	4,977	3,561	4,541	3,502	2,987	3,201	.....	.....	.....	.....	.....	10,632
1919	1	.....	.....	.....	.....	1,489	1,180	1,035	1,055	1,064	1,094	1,517	2,268	.....	.....
	2	.....	.....	.....	.....	1,068	1,110	1,005	1,223	860	1,097	988	1,330	.....	.....
	3	.....	.....	.....	.....	1,330	1,201	1,191	1,236	1,156	1,579	1,041	1,381	.....	.....
	Month.	.....	.....	.....	.....	3,886	3,491	3,231	3,514	3,081	3,770	3,545	4,979	.....	11,300
1920	1	899	933	1,035	1,946	1,321	1,118	1,072	942	895	1,323	955	1,407	.....	.....
	2	1,893	1,280	2,009	1,449	905	1,161	1,017	953	1,017	1,291	885	1,626	.....	.....
	3	995	875	1,708	1,364	1,226	982	1,288	1,197	1,456	1,161	1,230	1,438	.....	.....
	Month.	3,787	3,088	4,752	4,759	3,452	3,260	3,377	3,092	3,367	3,775	3,070	4,471	44,250	10,624
1921	1	1,589	1,071	1,082	1,113	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	2,061	1,319	1,385	1,230	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	1,271	1,020	1,529	1,406	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Month.	4,920	3,410	3,996	3,749	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average[2] to Apr. 30, 1921	1	(9) 1,747	(9) 1,324	(10) 1,500	(11) 1,301	(11) 1,300	(11) 1,235	(11) 1,113	(11) 1,043	(11) 1,046	(10) 1,205	(10) 1,174	(10) 1,354	.....	.....
	2	1,862	1,363	1,449	1,307	1,137	1,180	1,029	974	1,041	1,157	1,149	(9) 1,390	.....	.....
	3	(8) 1,544	1,218	1,594	1,191	1,446	1,179	1,126	1,130	(10) 1,079	1,278	1,251	1,571	.....	.....
	Month.	5,154	3,905	4,543	3,799	3,883	3,594	3,268	3,147	3,166	3,639	3,575	4,315	45,987	11,055
Average miles per hour.	1	7.3	5.5	6.2	5.4	5.4	5.1	4.6	4.3	4.4	5.0	4.9	5.6	.....	.....
	2	7.8	5.7	6.0	5.4	4.7	4.9	4.3	4.1	4.3	4.8	4.8	5.8	.....	.....
	3	5.8	6.1	6.0	5.0	5.5	4.9	4.3	4.3	4.5	4.8	5.2	6.0	.....	.....
	Month.	6.9	5.7	6.1	5.3	5.2	5.0	4.4	4.2	4.4	4.9	5.0	5.8	5.2	4.5

[1] See footnote, p. 29.
[2] Assuming January to have been average (5,401.6 miles) as averaged to 1918.
[3] Numbers in parentheses indicate number of records on which average is based. Monthly normal is sum of decade averages.

It is, perhaps, of first importance to note that the total wind movement by years varies only within somewhat narrow limits. For the seven years for which there are almost complete records the mean variation from normal is only 3.7 per cent of the total movement, while the Colorado Springs station shows an average variation of 5.1 per cent during the eight years 1910 to 1917, inclusive. The variation between growing seasons is even less important. For the 11 complete growing seasons the local station shows an average variation of 2.7 per cent of the total movement, while Colorado Springs for eight years shows an average variation of 7.5 per cent, the growing season on the plains being thus more variable than the year as a whole. The similarity of different growing seasons speaks for the importance and stability of the mountain and valley breezes, as well as for the practical immunity of the station to cyclonic influences which express themselves during the summer in the form of southerly winds. Apparently the least variation is to be expected in the last decade of June, when the influence of insolation is probably the greatest.

It is noted that the period of greatest calm, when the wind drops to an average velocity of 4.1 miles per hour, is at the middle of August, which also represents the climax of the summer rainy period, or at least a period when rains seldom fail. The cloudiness at this season reacts, of course, to retard the convectional flow of the mountain and valley breezes, while the cumulative effects of summer temperatures have doubtless at this time brought about the nearest approach to equilibrium of mountain and valley radiation.

From the middle of August to the end of the year the wind velocities gradually increase without important variation, and the maximum velocities are recorded during the second decade of January. This must be related to the general cosmic conditions. These are "anticyclonic" winds, blowing toward the centers of low-pressure areas, which during the winter almost invariably take a route across the southern portion of the United States. Anticyclonic winds are generally more violent than those in advance of the storm area, and only the anticyclones are of importance at the control station, because cyclonic winds during the winter season are locally opposed to prevailing mountain breezes, which result from higher temperatures on the plains.

Further evidence of the character of the winter winds at Fremont is found in the fact that they suffer a decline during February and are again important in March. In other words, they reach, locally, their greatest strength just before and just after the cyclonic storms have reached their southernmost course, which is normally in February. And they are probably less violent winds in February than in January or March, because the storm centers are farthest away in February. Their more northerly origin in February might be thought to affect their local force at the control station, but when other stations show the same feature this point loses significance.

The important biological fact is, then, that the winds coming during the coldest part of the winter, when practically all mountain soils are frozen, are most violent and incessant of any during the whole year, are dry because they are anticyclonic, and are of an especially inju-

rious character on the eastern slope of the Rocky Mountains, because in descending the slope they increase in temperature and in desiccating power. These winds not only fail to bring moisture with them or to precipitate any on the eastern slope, but they sometimes melt and always evaporate the snow which may have fallen in advance of their occurrence. Vegetation, then, is not only exposed, but the soil is denied the protection of a snow blanket which might retard its freezing, and the soil-building humus of the previous season's accumulation is frequently moved from exposed slopes to easterly slopes or canyon bottoms.

There is not the slightest doubt that this combination of conditions, in which anticyclonic winds are the chief element, comprises a very serious obstacle to forest growth in the Pikes Peak region, and that its analysis in relation to forest types may be of prime importance. Elsewhere along the eastern slope of the Rockies similar conditions may prevail, though it is doubted whether any locality can show such a powerful combination existing as a normal winter condition. Further back from the plains, at higher elevations, and on the western slope of the main range the westerly winter winds combine far less effectually for the destruction of vegetation and soils.

Considering the winter periods during which evaporation, as well as wind movement, has been measured, it is found that evaporation is not always rapid when wind velocities are high. When the mean temperatures are below freezing the amount of evaporation is so strongly influenced by the length of thawing periods that at this season, more perhaps than at others, the temperature may be said to affect the rate of evaporation more strongly than does the wind. In order to show, therefore, that high winds do cause excessive evaporation it is necessary only to show that they do not have a depressing effect on temperatures. This has been done by comparing the wind movements and temperatures for the 78 decades of record during December, January, and February. It has already been shown in Table 2 that the average mean temperature for these three months is essentially uniform. The comparison indicates that with mean wind velocities of 100 miles per day the mean temperature is 23.5°; for velocities of 150 miles, 25.0°; and for velocities of 200 miles, 26.1°. No doubt this power of winter winds to increase the temperature would be much more apparent if individual days were considered, as the decade which witnesses a very strong anticyclone may also cover the cyclone and the very low temperatures which often follow snowfall. It is, however, very certainly the tendency for higher temperatures to accompany the higher wind velocities, even though exceptions to this rule are very numerous.

The important thing is, then, that sometime during each winter wind movements occur which approximate velocities of 10 miles per hour over a period of a decade, and that these winds are always of westerly origin. Such velocities do not appear excessive, and, indeed, examination of the automatic record shows that excessive velocities seldom occur. A maximum of about 27 miles per hour is the highest record that thas been specifically noted, and over a period of 12 or 24 hours an average of 20 miles per hour is unusual. Even excessive movement for a day or two at a time is not likely to induce

sufficient evaporation to cause any apparent injury to trees. It is the continuity of these winds that makes them dangerous, and probably the decade is the shortest period that need be considered in this connection.

Only one additional feature of the record need be noted. Although there is a general decline in the average velocities from the end of April to August, there is a somewhat sharp rise at the end of May, continuing into June, which is nearly always associated with lack of precipitation. Whether the dry winds occurring at this season are actually injurious or not depends, no doubt, primarily on the reserve moisture of the soil. On the other hand, if the dryness occurs when the season, so far as temperature is concerned, is well advanced, as in 1917, a day or two of even moderately high winds with a high evaporating rate may have a very noticeable influence. On June 29, 1917, wilting of herbaceous vegetation, in general, and of some new shoots on conifers, was noted, although the soil was by no means dry, and the recorded velocity for the day was only 6.2 miles per hour.

This late spring dry period, with moderately high winds, is especially injurious to newly planted trees, and it may well be concluded that it has an indirect relation to forest types in so far as it tends to preclude the germination of seeds early in the season. It can not be said that any difference in this respect has been noted between different sites and exposures. When the atmosphere is lacking in moisture and is freely circulating, even the most protected situations seem to suffer superficial drying so quickly that germination is postponed until the beginning of the frequent summer rains, usually about July 15. This fact may create special problems in comparing the species in the Pikes Peak region, and it may be said that spring dryness has a bearing on the selection of the species which shall survive through the autumn drought.

Wind movement in the various forest types.—In Table 13 all the available data on wind movements are given. As the stations having this record are relatively few in number, it has not been thought necessary to consider the local stations apart from those lying at a greater distance from the control station, and hence subject to altogether different influences. Neither is it necessary to separate those stations at which the anemometer has been placed a considerable distance above the ground from those at which for a special reason the surface circulation has been measured, although in comparing the results this factor should be kept in mind. Inasmuch as the period of observation is very different for different stations, and at most of them is not over 2 or 3 years in length, the method has been followed throughout of giving the actual mean monthly movement for each station, and the percentage relation which this bears to the movement at the control station for the same period. These percentages might then be related to the "average" movement for the control station, as shown in Table 12, but it is doubted whether this computation would have any additional value. As the matter of primary interest is not wind, but rather its influence on evaporation, the main intent at this stage of the discussion is to show relative wind movements in a rough way only.

TABLE 13.—*Comparative wind movements.*

Station No.	Type.	Locality.	Elevation above ground.	Period of observations.	Datum.	By months, in total miles, and percentage ratios to the control station.												Total annual.	Total growing season.[1]
						Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
			Feet.																
C-1	Plains	Pikes Peak.	50	Feb. 1, 1910, to Jan. 31, 1918.	Miles	6,014	5,473	6,715	6,166	6,076	5,031	4,378	4,387	4,377	5,255	4,740	5,643	64,255	15,282
					Percent.	111	141	148	166	158	138	133	141	138	146	130	134	139.5	137.3
M-1	Western yellow pine	do	8	Mar. 1, 1915, to July 20, 1918.	Miles	4,018	3,497	3,954	2,862	3,187	2,473	2,204	2,089	2,313	3,055	3,395	4,330	37,375	7,522
					Percent.	83	76	83	80	79	67	66	70	72	79	89	85	78.0	68.1
F-2A	do	do	20	Mar. 1, 1910, to Feb. 29, 1912.	Miles	6,244	3,384	4,093	3,222	3,155	3,076	2,287	2,548	2,434	2,498	4,128	3,123	40,192	8,854
					Percent.	106	91	90	84	80	81	71	79	76	75	95	87	86.1	77.6
F-12	do	do	7	Mar. 4, 1915, to Feb. 29, 1916.	Miles	5,152	2,939	2,052	2,350	2,845	2,868	2,525	1,797	2,509	2,347	4,413	4,406	36,204	7,881
					Percent.	97	83	71	69	77	77	75	63	73	72	92	90	80.1	71.7
F-6	Limber pine	do	1½	Mar. 11, 1915, to Feb. 29, 1916.	Miles	3,330	2,071	2,335	1,406	1,666	1,574	1,360	912	1,167	1,470	3,788	3,793	24,871	4,140
					Percent.	63	58	74	42	45	42	40	31	34	44	83	78	54.8	37.4
F-7-8	Douglas fir (open).	do	1	Apr. 1, 1916, to Mar. 4, 1918.[2]	Miles	715	842	830	452	364	564	308	209	484	423	551	852	19,783	3,728
					Percent.	52	54	53	37	30	43	25	17	43	34	48	50	41.5	30.3
F-9	Douglas fir (uncut).	do	1	do	Miles	1,100	1,167	468	452	612	669	261	224	244	842	553	1,371	7,962	1,225
					Percent.	24	22	9	12	16	18	8	7	8	20	17	26	16.3	10.8
F-14	Douglas fir (half cut).	do	1	do.[3]	Miles	498	576	0	436	295	339	166	100	196	458	265	803	12,396	2,011
					Percent.	38	34	0	31	25	29	16	11	20	33	27	43	26.8	19.3
F-15	do	do	1	do.[4]	Miles	956	720	99	308	582	405	197	209	357	725	545	752	17,566	2,789
					Percent.	48	36	5	33	38	31	17	20	33	46	45	46	33.1	24.1
W-A1	Douglas fir, north.	Rio Grande	5	Nov. 1, 1910, to Aug. 31, 1918.	Miles	1,488	1,447	1,787	1,896	2,167	1,983	1,657	1,544	1,431	1,488	1,370	1,354	19,612	5,661
					Percent.	27	36	38	51	55	55	51	50	45	41	38	32	42.2	51.6
F-3A	Engelmann spruce, canyon.	Pikes Peak.	20	Mar. 1, 1910, to Feb. 29, 1912.	Miles	2,742	1,660	2,081	1,788	1,730	1,649	1,256	1,339	1,294	1,359	2,100	1,603	20,601	4,741
					Percent.	46	45	46	47	44	44	39	41	40	41	48	45	44.2	41.5
F-16	Timber line	do	10	Oct. 1, 1916, to Feb. 28, 1918.	Miles	12,933	10,579	11,640	8,324	5,877	6,085	4,459	4,813	5,160	9,924	8,452	15,477	103,722	17,003
					Percent.	278	208	224	230	255	159	129	153	181	237	253	296	216.7	150.0
W-D	Engelmann spruce, burn.	Rio Grande	20	June 1, 1913, to Aug. 31, 1918.	Miles	5,685	4,678	6,069	5,128	5,015	4,387	3,556	3,360	3,562	4,765	4,202	5,034	55,441	12,490
					Percent.	117	102	127	146	128	120	109	109	112	129	123	109	119.0	113.3
F-11	Lodgepole pine.	Southern Wyoming.	6	Mar. 21, 1916, to Sept. 10, 1918.	Miles	4,944	4,965	4,679	3,269	2,998	2,528	2,181	2,146	2,322	3,431	3,338	5,469	42,270	7,611
					Percent.	106	96	93	90	73	69	66	69	76	82	100	105	87.3	68.6

[1] Growing-season totals secured by considering first decade of September only, except stations F-14 and F-15, where the single available record for September is used. Fractional miles in original records throughout rounded off.

[2] First decade of each month only. Annual totals approximated by multiplying decade sums by 3.

[3] Second decade only.

[4] Third decade only.

If an examination is made first of the Colorado Springs station, which may perhaps give a better conception of the wind movements of the region than even the control station, because of the free exposure of the former, it is seen that, for the whole year, the wind movement is much greater than that at the control station, and greater than that of any of the mountain stations, except that at timber line on Pikes Peak. The growing-season total bears almost the same relation to the control station as the total for the whole year. The Plains station has a low ratio to the control station during the early winter months, November to January, which may mean that the location of the control station gives winds at that time a magnified local effect. The Plains station has relatively the highest winds during the spring, probably because it is more susceptible to the winds which blow from all directions toward storm centers during the spring period. Actually, the most severe season on the Plains must be just before the end of winter and before thawing has become general.

The Monument yellow-pine station is only 20 miles from Colorado Springs, but being in the edge of the hills is fairly well protected from north-south currents. This station shows distinctly mountain characteristics, but scarcely more than half the total movement recorded on the Plains. Part of this difference is no doubt due to the elevation of the anemometer, which is barely above the top of the surrounding oak-brush clumps. The relatively high values at this station throughout the entire winter period define the degree of exposure on the west. It is not doubted that, with a similar local exposure of the anemometer, this station would show winter values just about the same as the control station. The evaporation attending such winds would be augmented by the higher temperatures in the pine belt, but their effect on vegetation would be decreased by the shortness of the soil-freezing period.

The local yellow-pine station (F–2) shows no great variation from the control station, such difference as exists being explicable, probably, by the wind-breaking power of the surrounding trees, which run up 30 to 40 feet higher than the anemometer. No doubt the high January ratio at this station was due to the wind blowing from certain directions so that the currents reached the anemometer unbroken. On the whole, it would be best to assume that the exposure, if the trees were not present, would correspond closely to that of the control station.

The record at the yellow-pine ridge station (F–12) is difficult to explain, inasmuch as both the soil of the ridge and the character of the growth thereon are suggestive of the most extreme wind exposure. Indeed, a few isolated days may be found when the velocities of west winds recorded here exceed those at the control station. On the whole, however, the movement is considerably less. The anemometer was placed high enough to be practically free from the influence of the surrounding trees, which are short and widely scattered. The deficit can be accounted for only by the position of the station on a bench of considerable area, which does not directly contribute to and in fact is out of the paths of the local convectional currents, which naturally hug the slopes and valley bottoms. The station can not be considered to represent so severe a wind exposure as the control station; but, if its longer period of soil freezing is considered, it represents, as will be seen later, a closer approach to the limiting conditions for yellow pine.

The west-slope limber pine station (F–6) shows scarcely more than half the movement recorded at the control station. The ratio is very low during the summer months when the prevailing winds are of easterly origin. The values of 74 to 83 per cent during some of the winter months are high, when it is considered that the anemometer was placed only 18 inches above the ground surface in a fairly dense forest. As the strongest winds blow against the face of this slope, this does not indicate any unusual velocities overhead, but it does indicate extremely severe conditions for reproduction.

The four north-slope Douglas fir stations (F–7–8, 9, 14, and 15), differing only in the weight of their forest cover, show clearly the ability of the forest to check surface-air movements. The ratios of each station to the control station are quite irregular, on account of the short periods involved, and because of the fact that during the winter months the anemometers at an elevation of only 1 foot may be completely stopped by accumulated snow. This rarely occurs for more than a short period, but of course may obliterate some of the highest wind movements. On the whole, the movement in the forest is seen to be scarcely more than one-third of that in the open; in the partly-cut forest it is two-thirds. The winter values are the highest, both absolutely and when related to the control station, because this slope is hardly at all sheltered from northwest winds. It is not difficult to believe that the wind that blows over the tops of the trees is here quite as strong as at any similar elevation in the locality.

The local spruce canyon site (F–3) shows much more wind than would be expected, even with the anemometer 20 feet above the ground and well into the tops of the young spruce trees. The ratios of movements here to those at the control station are perhaps more constant than for any other station. This site is scarcely more than 400 feet from the control station, but in a narrow V-shaped canyon bottom, which could not possibly be called "exposed." The fairly good velocities attained here show clearly the importance of the mountain and valley breezes, of which the former particularly is always most noticeable in a canyon bottom. This canyon, moreover, appears to receive its due share of pressure from the stronger west winds of winter.

The timber-line station (F–16) gives a fair impression of the movements in the higher atmosphere. Pikes Peak to the south rises at a sharp angle nearly 3,000 feet higher than this station, and the slope is by no means rounded. The site, however, does not seem to be exempt from the influence of winter winds, although the movement in the summer is relatively moderate. West and northwest winds obtain a perfectly free sweep over all topographic features on that side. The resultant velocities at the station, which is unprotected by any timber, tax the credulity. The January ratio of 278 per cent would mean, when related to the control station averages, a mean velocity of about 20 miles per hour for that month. The following data have been picked from the record of 17 months:

	Velocity, miles per hour.
Highest 10 days, Dec. 11 to 21, 1916	26.0
Highest 5 days, Dec. 21 to 26, 1916	31.4
Highest single day, Jan. 27, 1917	42.0
Highest six hours, Nov. 30, 1917	44.9
Highest single hour, Dec. 3, 1916	49.0

It is seen from these special data, as well as from Table 13, that this station, except for the four summer months, is exposed to wind forces more than twice as strong as those at the control station. Hence these winds are strong enough to move snow and soil and actually blast off the exposed portions of trees as with a sand-blast. There is no doubt in the mind of the writer that here the upper limit of timber growth is set by the mechanical effects of the wind and only indirectly by temperature conditions. The spruce and bristlecone pine trees which form the upper fringe of the forest are severely exposed during eight months of the year, and during much of this time they are cut off from soil moisture by the freezing of the ground. Although low temperatures greatly modify the drying power of the violent winds, it will be seen later that these winds are by no means incapacitated for doing damage.

The high spruce station at Wagon Wheel Gap (W–D), though fully exposed in an old burn, shows by no means the wind velocities that have just been described. Its velocities are only a fifth greater than those at the control station, the lowest ratios occurring at midsummer. The immunity to high wind is doubtless characteristic of the vicinity of Wagon Wheel Gap, and not due to any special features of the exposure, for even at an elevation corresponding to F–16 (namely 11,500 feet) no excessive velocities have been recorded, and at 12,000 feet, on the highest ridge of the locality, the evidences of injury from wind are confined to a small flat at the very top, where the movement of snow is most easily accomplished.

Turning now to the Douglas fir station in this locality (W–A1), protected by the walls of a basin which drains to the east, it is seen that the annual movement corresponds closely to that of the fully exposed north-slope station at Fremont (F–7–8), but that the winter velocities of the former are much lower and are counterbalanced by greater movement during the spring and summer. In fact, Station W–A1 is the only one in the list which shows higher velocities in summer than in winter, relative to the control station. Only the winter velocities are of any import. It will later be seen that, in combination with low temperatures but a drier atmosphere, these light winds have considerable power for evaporation; but during the winter months there is less of this influence than is shown at the control station.

Finally, a glimpse may be had of the conditions which characterize the lodgepole forest of southern Wyoming (F–11). This station is only partly exposed and receives a great deal of protection from the forest on the north and west. Hence the relatively high velocities of December and January bespeak a very great disturbance of the atmosphere; and, even though the ratios decline during the latter part of the winter, it is difficult to concede that the exposure of trees is any less severe in this locality than at the control station. During the summer the wind movement might best be compared with that of the yellow pine type at Monument. However, it must be remembered that this lodgepole locality, and every other lodgepole locality which was examined in connection with air temperatures, is characterized by very cold winters, and it will be seen later that, by actual test, this practically nullifies the evaporation at Foxpark.

It should be brought to attention that the data presented in no case refer to wind conditions at the level of the tree top, and that,

for the most part, direct comparisons of the sites are only approximate because of the varying elevations of the exposed anemometers. Every such consideration would lead to the belief that the several sites in the vicinity of Fremont would be quite closely comparable as regards total wind movement 40 or 50 feet above the ground, and therefore that the exposure of the growing tops of the trees, the portion most sensitive to desiccating influences, is not essentially different in different sites. The general air movement which characterizes the locality, considered in connection with soil freezing, is probably more important in fixing the types of forest than are the specific velocities which have been measured. On the other hand, high elevations doubtless experience much stronger winds than do the middle elevations; the Plains region, slightly stronger; the Wyoming locality, stronger winter winds; and the Wagon Wheel Gap locality, winter winds of less importance, when like exposures are compared.

ATMOSPHERIC HUMIDITY.

Atmospheric humidity is doubtless of some importance in any ecological study, but nowhere more so than in a study of evergreen trees, which are influenced by evaporation and transpiration during the winter as well as the summer. In this relation, the saturation deficit is a much more valuable criterion than either vapor pressure or relative humidity, as the "deficit" expresses at once the capacity of the atmosphere for additional moisture, without further reference to temperature. In other words, a lack of vapor in the atmosphere, amounting, for example, to 0.100 inch (this being the difference between the actual and possible pressures) should induce about the same rate of evaporation whether the air temperature be 40° or 100°. The greater deficits are, of course, likely to be encountered at high temperatures.

The correct measurement of the moisture of the atmosphere is one of the most difficult which a meteorologist is called upon to perform. It is almost impossible to eliminate the personal element in securing a depression of the wet bulb of the psychrometer, for there is constantly a tendency to fail to secure the greatest possible depression. To make the situation more difficult, there is no hygrograph, or automatic instrument for this purpose, which is at all precise. One is compelled to depend upon such psychrometer readings as can be taken in estimating the mean moisture for whole days or longer periods, and must never forget that even these observations are fallible. In spite of the most conscientious effort in the field, therefore, the humidity data here presented can show only approximate mean conditions.

Although the ultimate interest is in vapor deficits, as related to evaporation, it will be worth while to examine first the absolute-humidity or vapor-pressure data, to determine whether there is any essential difference between adjacent sites other than that induced by variations in air temperature. Even this is difficult to determine, as is realized when one notes the rapid changes in vapor pressure with changes in temperature at a given point. However, as vapor is distributed through the atmosphere very rapidly, local excesses or deficits tend to be nullified. Hence it is to be expected, at least for the several sites immediately adjacent to the Fremont station, that there will be little variation in absolute humidity.

TABLE 14.—*Mean vapor pressures at the control station, from psychrometer readings at 7 and 8 a. m.*

[From table for 21.42 inches barometric pressure prepared by B. C. Kadel, United States Weather Bureau.]

Year.	Decade.	Vapor pressure in inches of mercury.													
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean annual.	Mean growing season.
1910	1	.....	.....	[1] 0.1067	[1] 0.1259	0.1460	0.2092	0.2445	0.3007	0.1828	0.1371	0.0939	0.0808	.....	.....
	2	.....	.....	.1079	.1320	.1508	.2272	.2572	.2932	.2715	.1454	.1000	.0743	.....	.....
	3	.....	.....	[1].1235	.1870	.2012	.2636	.2920	.2347	.1872	.1038	.0909	.0733	.....	.....
	Month.	.....	.....	.1130	.1483	.1671	.2333	.2654	.2749	.2138	.1280	.0949	.0760	.....	0.2505
1911	1	[1] 0.0490	0.0529	.0867	0.1269	0.1588	0.1579	0.2896	0.2649	0.2657	0.1842	0.0937	0.0515	.....	.....
	2	.0866	[1].0645	.0889	.0912	.1256	.2647	.3279	.3386	.2536	.1315	.0883	.0510	.....	.....
	3	.0893	.0457	.0942	.1437	.1795	.2373	.2935	.2473	.2258	.1145	.0477	.0348	.....	.....
	Month.	.0754	.0550	.0901	.1206	.1554	.2199	.3033	.2824	.2484	.1424	.0766	.0454	0.1512	0.2687
1912	1	0.0263	0.0512	0.0848	0.0997	0.1907	0.2493	0.2813	0.3197	0.2035	0.1508	0.0887	0.0455	.....	.....
	2	.0186	.0582	.0766	.0980	.1617	.2284	.3361	.3198	.1493	.1023	.0681	.0485	.....	.....
	3	.0425	.0434	.0750	.1099	.2011	.2974	.3779	.2640	.1260	.1113	.0455	.0304	.....	.....
	Month	.0392	.0512	.0787	.0925	.1850	.2584	.3333	.3000	.1596	.1211	.0674	.0411	0.1440	0.2877
1913	1	0.0412	[1] 0.0437	.0660	0.0793	0.1323	0.2149	[1] 0.3090	[1] 0.2741	0.2817	0.1347	0.0958	0.0749	.....	.....
	2	.0389	.0548	.0615	.1001	.1366	.2304	[1].3060	.2434	.1927	.1057	.1109	.0601	.....	.....
	3	.0515	.0457	.0675	.0983	.2050	.2339	.2368	.2428	.1375	.0904	.0744	.0474	.....	.....
	Month.	.0441	.0482	.0650	.0926	.1595	.2264	.2824	.2531	.2039	.1093	.0937	.0604	0.1339	0.2573
1914	1	0.0701	.....	.....	0.1121	0.1515	[2] 0.2145	0.3328	[1] 0.3426	0.3076	0.1420	0.0868	0.0713	.....	.....
	2	.0801	.....	.....	.1149	.1895	.2735	.3441	.3021	.2208	.1081	.0569	.....	.....	.....
	3	.....	.....	.....	.1434	.1996	.2163	.3549	.2412	.1500	.1400	.0780	.....	.....	.....
	Month.	.0751	.....	.....	.1235	.1808	.2348	.3443	.2935	.2261	.1301	.0739	.....	.....	0.2930
1915	1	.....	.....	[1] 0.0742	0.1503	0.1336	0.2014	0.2409	0.2724	0.2236	0.1453	0.1147	0.1070	.....	.....
	2	.....	.....	.0736	.1516	.1428	.1895	.2667	.2945	.2078	.1470	.0738	.0759	.....	.....
	3	.....	.....	.1183	.1824	.1735	.2744	.2860	.2576	.1934	.1169	.0859	.0934	.....	.....
	Month.	.....	.....	.0896	.1614	.1507	.2218	.2652	.2743	.2083	.1358	.0915	.0921	.....	0.2507

1916	1	0.0698	0.1040	0.0906	.0900	0.0908	0.1661	0.2683	0.2844	0.2243	0.1718	0.0741	0.0645	.....	.....
	2	.0754	.0624	.0564	.0939	.1393	.1938	.2789	.3022	.1649	.1539	.0656	.0478	.....	.....
	3	.0942	.0646	.0731	.1306	.1075	.1533	.2770	.2642	.1333	.1045	.0455	.0428	.....	.....
	Month.	.0867	.0905	.0734	.1048	.1124	.1710	.2748	.2829	.1742	.1421	.0617	.0514	0.1355	0.2412
1917	1	0.0575	0.0640	0.0504	0.0790	0.1260	0.1477	0.2295	0.2513	0.2440	0.1455	0.0628	0.0598	.....	.....
	2	.0550	.0629	.0612	.1365	.1543	.1692	.2408	.2783	.2110	.0885	.0880	.0779	.....	.....
	3	.0415	.0696	.0699	.1058	.1685	.1837	.2710	.1895	.1547	.0854	.0758	.0648	.....	.....
	Month.	.0510	.0652	.0573	.1071	.1502	.1669	.2478	.2381	.2032	.1058	.0755	.0706	0.1282	0.2205
1918	1	0.0700	0.0553	0.0912	0.0901	0.0985	0.1940	0.2950	0.2720	0.2120	.....	.....	.....	.....	.....
	2	.0536	.0490	.0799	.1094	.0942	.2423	.2872	.2562	.1856	.....	.....	.....	.....	.....
	3	.0710	.0706	.1090	.1005	.1469	.2576	.2670	.1956	.....	.....	.....	.....	.....	.....
	Month.	.0652	.0574	.0988	.1000	.1143	.2313	.2825	.2404	.....	.....	.....	.....	.....	0.2481
Average to Sept. 20, 1918	1	0.0577	0.0618	0.0613	0.1026	0.1365	0.1950	0.2768	0.2869	0.2384	0.1514	0.0688	0.0707	.....	.....
	2	.0626	.0620	.0758	.1204	.1439	.2243	.2939	.2923	.2063	.1228	.0814	.0622	.....	.....
	3	.0650	.0699	.0901	.1335	.1759	.2353	.2951	.2374	.1635	.1084	.0680	.0553	.....	.....
	Month.	.0619	.0613	.0826	.1188	.1529	.2182	.2888	.2711	.2027	.1269	.0794	.0625	0.1439	0.2575

[1] Contains element of estimate because of the omission of some of the daily observations.
[2] Beginning of 8 a. m. observations.

Vapor pressures at the control station.—In Table 14 are presented the records of vapor pressures for the control station, by decades, up to September, 1918. These vapor pressures have been computed from a table prepared in 1911 by B. C. Kadel, of the Weather Bureau, for a barometric pressure of 21.42 inches, which is the mean for Wagon Wheel Gap, but slightly below the mean for Fremont.

It will be noted that up to June, 1914, these records pertain to conditions prevailing at 7 a. m., while thereafter the psychrometer readings were taken at 8 a. m. This change has probably had a very slight effect on the values, increasing the later ones by about 0.0050 inch.

As these data are only of indirect interest in the study, their detailed consideration is hardly necessary. However, a few interesting facts from the meteorological standpoint may be noted.

(1) The amount of vapor in the air varies greatly at times from one decade to the next. This is not surprising in view of variations in cloudiness, wind direction and velocity, and other conditions which are related. However, it is surprising to find that different years may vary by a margin as great as 25 per cent. In general, these variations show little relation to mean temperatures; or, if they show any such relation, they indicate that high vapor pressures tend to lower temperatures, rather than that high temperatures permit high humidity. This is more plainly true of growing seasons than of whole years. Some of this variation may be ascribed to changes in observers and to consequent changes in the standard of psychrometer readings.

(2) The seasonal variation, as indicated by the averages for eight years, or indeed by most of the individual years, keeps pace with the rise and fall of temperature, but is to some extent modified by prevailing wind directions and velocities. The highest humidities are recorded in the latter half of July, with the highest temperatures; but the middle of August is likewise a moist period, with low winds and prevailing cloudiness, as previously mentioned.

As humidity readings at other stations in the same locality as the control station have always followed those at the control station by an interval varying from a few minutes to two hours, and as it is proposed to use the 8 a. m. humidity as a measure of the mean humidity for whole days, it is necessary to determine to what extent the humidity varies during the day. In Table 15 the data are given for representative months from March, 1910, to February, 1912, during which time observations were made daily at 7 a. m., 1 p. m., and 7 p. m.

TABLE 15.—*Vapor pressures at the control station at various hours, April, 1910, to January, 1912.*

[Average vapor pressures in inches.]

Hour.	January.	April.	July.	October.	Mean annual.	Increase over pressure at 7 a. m.	
						Amount.	Per cent.
7 a. m.	0.0573	0.1244	0.2844	0.1352	0.1528	.....	.....
1 p. m.	.0900	.1594	.3128	.1726	.1812	0.0284	19
7 p. m.	.0670	.1393	.3022	.1457	.1636	.0108	7

Table 15 indicates that there is an increase in the vapor pressure, corresponding to the rise in temperature from 7 a. m. to 1 p. m., and amounting on the average to 0.0284 inch, or 0.0047 inch per hour, and that most of the increase has been lost by 7 p. m. There is every reason for supposing that the lowest vapor pressure of the day would be recorded with or shortly following the minimum air temperature, for, if this is lower than the dew point, some of the atmospheric moisture is certain to be precipitated as dew or frost. The humidity at 7 a. m. is, then, probably less than the mean humidity for the day, as the temperature at that hour is slightly below the mean temperature. The 8 a. m. humidity, however, can not miss the mean for the day by a very wide margin.

To estimate the probable increase from 7 a. m. until 1 p. m., at any other station, it is best to use the average figure, 0.0284 inch, representing the whole year; for, though October and January do not agree in the amount of this change, October, 1910, and October, 1911, were by no means uniform in this respect.

Vapor pressures at other stations near the control station.—Stations F–2 and F–3, which are situated only a few hundred feet from the control station, but represent very different sites, were observed daily during the first two years of this project and only a few minutes later than the control station. Hence their humidities are comparable, with little or no correction for time. The variations from the control station, by months, are shown in Table 16.

TABLE 16.—*Departure of vapor pressures at two near-by stations from those at control station, 1910–1912, in inches of mercury.*

[All records obtained 20 feet above ground.]

Station No.	Type.	January.	February.	March.	April.	May.	June.	July.
F-2A.....	Yellow pine, south slope.	−0.0015	−0.0021	−0.0007	−0.0054	−0.0056	−0.0080	−0.0071
F-3A.....	Canyon spruce.....	+.0045	+.0031	+.0063	+.0193	−.0036	−.0195	−.0070

Station No.	Type.	August.	September.	October.	November.	December.	Year.	Growing season.[1]
F-2A.....	Yellow pine, south slope.	−0.0097	−0.0085	−0.0158	+0.0007	−0.0008	−0.0053	−0.0082
F-3A.....	Canyon spruce.....	−.0186	+.0043	−.0102	−.0005	+.0021	−.0016	−.0158

[1] Based on arithmetic means of 10 decades.

It is indicated that the atmospheric humidity over the south-slope station is always less than at the control station, with the possible exception of November. The same is true of the canyon site which has developed spruce, if the year as a whole is taken; but from December to April this site consistently shows higher humidity than the control station. The amount of excess is generally more than could possibly be accounted for by the difference in time between the observations.

For the growing season at least, it is safe to say that the vapor pressure 20 feet from the ground in the pine stand is less than at the control station, and in the spruce stand less than in the pine. Whether the forest growth has any direct relation to this fact may be seriously questioned. It is believed that marked deficits during

the growing season are due simply to the fact that these sites do not feel the effect of the diurnal valley breeze quite so early as the control station, these breezes carrying somewhat more moisture than the local air.

Certain data are given in Table 17 for somewhat more distant stations covering a later period of two years, when observations at the control station were taken at 8 a. m., and those at the outlying stations from one-half to one and one-half hours later, the interval being longer in winter than in summer. At all these outlying stations the psychrometer was swung as close to the ground as possible.

TABLE 17.—*Departure of vapor pressures near the ground, in north-slope Douglas fir type, from those at the control station, in inches of mercury.*

Station No.	Cover condition.	January.	February.	March.	April.	May.	June.	July.
F-7-8	Clear cut	−0.0036	+0.0050	+0.0046	+0.0038	+0.0108	+0.0019	+0.0064
F-14	Half cut	−.0013	−.0014	−.0036	−.0032	+.0055	+.0112	+.0305
F-15	do	−.0027	+.0005	+.0026	−.0028	+.0021	−.0007	+.0243
F-9	Uncut	+.0001	+.0036	+.0013	−.0053	+.0067	+.0041	+.0146
Average		−.0019	+.0019	+.0012	−.0019	+.0068	+.0041	+.0190

Station No.	Cover condition.	August.	September.	October.	November.	December.	Year.	Growing season.[1]
F-7-8	Clear cut	+0.0309	+0.0214	+0.0067	+0.0089	−0.0088	+0.0073	+0.0139
F-14	Half cut	+.0321	+.0060	−.0006	+.0031	−.0081	+.0058	+.0227
F-15	do	+.0065	+.0083	−.0091	+.0082	−.0028	+.0029	+.0089
F-9	Uncut	+.0210	+.0126	+.0026	+.0078	−.0014	+.0058	+.0132
Average		+.0226	+.0121	−.0001	+.0070	−.0053	+.0054	+.0149

[1] Growing-season means computed by adding three times the June, July, and August differences to the September difference and dividing the total by 10.

The great irregularity of the relations indicated by the above data is difficult to account for. It should be understood that humidity at each of the first three stations was measured during different decades of each month; that is, during one decade a month for each station. The record for Station F–9 is complete, and therefore might be compared with the average of the first three stations. However, even this comparison does not help to clarify the results. Every effort was made to eliminate discrepancies by using the same psychrometer at all stations, and by daily reversal of the order of observations. Hence the average time is essentially the same for each of the four stations.

All of the annual differences show higher humidity at these stations than at the control station. The increase in humidity during the morning hours is due to the rise in temperature, or to the setting up of the mountain breeze, or to both. In either case the greatest change is likely to occur in the early part of the day, and especially in summer between 8 and 9 a. m. Hence, the generally higher humidity at these stations, as well as the great excess during the growing season, may be wholly accounted for by the difference in time between these stations and the control station. On the other hand, the variations between the four stations are unaccountable, except on the ground of variations in the amounts of sunlight at the points of observation and of the impossibility of entirely shielding the psychrometer from this influence. Sunlight on the psychrometer has the effect of lessening the wet-bulb depression and thereby making the humidity appear higher than it is.

On the whole, there is no indication that the humidity at these forest stations near the ground is measurably different from that 20 feet above the ground in the open position of the control station.

Vapor pressures in central and southern Colorado.—The control station may now be compared with the only other station in this series for which dependable humidity records are available (Table 18). The stations are at similar elevations, and the record covers nearly seven years. The later time of observations at Wagon Wheel Gap—9 a. m.—should tend to bring out higher vapor pressures than at the control station.

TABLE 18.—*Absolute and comparative humidity at W–A1 (Wagon Wheel Gap north-slope Douglas fir).*

Datum.	January.	February.	March.	April.	May.	June.	July.
Actual 9 a. m. vapor pressure...	0.0537	0.0562	0.0734	0.0995	0.1165	0.1849	0.2792
Compared with 8 a. m. at control station.....	−.0066	−.0050	−.0049	−.0133	−.0345	−.0314	−.0099

Datum.	August.	September.	October.	November.	December.	Year.	Growing season.
Actual 9 a. m. vapor pressure...	0.2605	0.1894	0.1149	0.0735	0.0506	0.1294	0.2363
Compared with 8 a. m. at control station.....	−.0101	−.0140	−.0118	−.0059	−.0118	−.0132	−.0168

The greatest difference between the two localities is seen to exist during May and June, when their temperature difference is least. This great deficit at Wagon Wheel Gap is due to the fact that the rainless period in May or June, or both, is much more marked than it is farther north and corresponds more closely to the conditions in the Southwest.

During other portions of the year the deficit at Wagon Wheel Gap is relatively uniform. It should, however, be pointed out that this deficit may not mean much higher evaporation rates at Wagon Wheel Gap, because the general temperature is here lower than at Fremont.

An examination of the different years at Wagon Wheel Gap, which are comparable with whole years at Fremont, shows that the variations from year to year are of almost the same magnitude as those at Fremont, but that the two series are by no means parallel.

Saturation deficits.—The question of humidity in combination with air temperatures may now be considered. It has been stated that the most direct expression for humidity, to bring out the relation of this condition to evaporation and transpiration, is the vapor deficit. In the following tabulation the vapor deficit has been computed by deducting the mean decade vapor pressure, determined by the daily observations at 8 a. m., from the saturation pressure, determined by reference to the mean temperature for the decade. If applied to single days, this method would be far from precise, because the humidity might strongly increase or decrease during a whole day. It is believed, however, that the 10 morning determinations of humidity in a decade give a very close approximation to the true mean humidity, and that the mean temperature is a sufficiently close measure of the mean saturation pressure for the whole decade. Of course, this method would err seriously if the temperature variations in a decade were very great.

TABLE 19.—*Mean saturation deficits at the control station, by decades (based on 8 a. m. vapor pressures and mean air temperatures).*

Year.	Decade.	Saturation deficits, in inches of mercury.													
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean annual.	Mean growing season.
1910	1	(1)	(1)	[2] 0.1123	[2] 0.0818	0.0998	0.1946	0.2515	0.1859	0.2708	0.2275	0.1481	0.1118	.....	.....
	2	.....	.....	.1227	.0829	.0977	.2592	.3178	.1812	.1719	.1251	.0736	.0963	.....	.....
	3	.....	.....	[2] .1095	.0906	.1124	.2073	.2582	.2225	.1691	.1411	.1341	.0411	.....	.....
	Month.	.....	.....	.1146	.0851	.1036	.2204	.2752	.1974	.2039	.1638	.1186	.0817	0.1564	0.2349
1911	1	[2] 0.0773	0.1044	0.1209	0.0881	0.1381	0.2959	0.1468	0.2384	0.1551	0.1150	0.0643	0.1140	.....	.....
	2	.1278	[2] .0463	.0807	.0847	.1808	.1403	.1089	.2001	.1420	.0869	.0919	.0278	.....	.....
	3	.1028	.0213	.0868	.0986	.1420	.2573	.1237	.1356	.1769	.0577	.0691	.0459	.....	.....
	Month.	.1026	.0599	.0958	.0905	.1532	.2312	.1264	.1896	.1580	.0856	.0751	.0620	0.1192	0.1802
1912	1	0.0735	0.0711	0.0408	0.1368	0.0432	0.1149	0.1646	0.1117	0.2202	0.1207	0.1240	0.0562	.....	.....
	2	.1025	.0616	.0553	.0569	.0807	.0525	.1251	.1041	.0929	.1493	.1376	.0787	.....	.....
	3	.1202	.0344	.0454	.0866	.1742	.0908	.0926	.2230	.0846	.0872	.1213	.0750	.....	.....
	Month.	.0996	.0564	.0471	.0934	.1018	.0861	.1263	.1423	.1326	.1220	.1276	.0701	0.1004	0.1300
1913	1	0.0345	[2] 0.0515	0.0751	0.0935	0.1088	0.0967	[2] 0.2526	[2] 0.2367	0.1448	0.1275	0.1188	0.0494	.....	.....
	2	.0846	.0613	.0670	.1523	.1646	.1602	[2] .1550	.2540	.1051	.0983	.1284	.0677	.....	.....
	3	.0921	.0248	.0851	.1336	.1734	.2139	.1702	.2264	.0818	.0840	.0937	.0606	.....	.....
	Month.	.0711	.0500	.0760	.1265	.1497	.1569	.1919	.2386	.1106	.1026	.1136	.0692	0.1206	0.1910
1914	1	0.1093	(1)	(1)	0.0545	0.1141	0.1741	0.0852	[1] 0.1426	0.1464	0.1574	0.1677	0.0265	.....	.....
	2	.0942			.0798	.0475	.1365	.1215	.2081	.1764	.1671	.1196	(1)	.....	.....
	3	(1)			.0712	.1515	.2481	.1063	.1669	.1954	.0965	.1222	(1)	.....	.....
	Month.	.1018	.....	.....	.0685	.1059	.1862	.1044	.1724	.1727	.1389	.1365	.....	.....	0.1536
1915	1	(1)	(1)	[2] 0.0114	0.0483	0.0491	0.0918	0.1614	0.1241	0.1762	0.1200	0.1453	0.0890	.....	.....
	2			.0465	.0792	.1304	.1746	.2011	.0893	.1418	.0771	.0601	.0387	.....	.....
	3			.0316	.0639	.0984	.1026	.1253	.1191	.1193	.2108	.0725	.0272	.....	.....
	Month.	.....	.....	.0299	.0638	.0928	.1230	.1614	.1111	.1458	.1384	.0926	.0508	.....	0.1366

1916	1	0.0892	0.0267	0.0798	0.0623	0.2006	0.1539	0.2469	0.1985	0.2136	0.1301	0.1547	0.0638	.....	.....
	2	.0190	.1110	.1975	.1204	.0647	.1929	.1933	.1422	.1308	.0522	.0358	.0475	.....	.....
	3	.0158	.0594	.1041	.0678	.2361	.3382	.2354	.1098	.1890	.1206	.1046	.0416	.....	.....
	Month.	.0405	.0655	.1264	.0902	.1694	.2283	.2355	.1488	.1778	.1016	.0983	.0507	0.1269	0.2025
1917	1	0.0928	0.0607	0.0438	0.0679	0.0215	0.1579	0.2262	0.2142	0.2028	0.1751	0.1851	0.0509	.....	.....
	2	.0329	.0500	.0418	.0492	.1173	.2070	.2304	.1001	.1361	.1585	.1042	.1144	.....	.....
	3	.0599	.0758	.0949	.0901	.0490	.3291	.2770	.2115	.1784	.0984	.1294	.1399	.....	.....
	Month.	.0621	.0612	.0614	.0657	.0621	.2313	.2456	.1823	.1724	.1407	.1396	.1029	0.1273	0.2156
1918	1	0.0526	0.0955	0.0960	0.0641	0.1749	0.1957	0.1550	0.2292	0.1120	.....	.....	.....	.....	.....
	2	.0153	.0662	.1145	.0402	.1945	.2927	.1422	.1866	.1415	.....	.....	.....	.....	.....
	3	.0226	.1104	.0914	.0999	.1632	.1983	.1970	.2279	.....	.....	.....	.....	.....	.....
	Month.	.0299	.0806	.1003	.0677	.1770	.2289	.1658	.2150	.....	.....	.....	.....	.....	0.1937
Average to Sept. 20, 1918	1	0.0756	0.0681	0.0725	0.0775	0.1056	0.1639	0.1878	0.1868	0.1824	0.1467	0.1385	0.0702	.....	.....
	2	.0682	.0611	.0908	.0828	.1198	.1795	.1773	.1629	.1376	.1143	.0939	.0873	.....	.....
	3	.0689	.0644	.0811	.0901	.1445	.2206	.1762	.1825	.1498	.1114	.1059	.0616	.....	.....
	Month.	.0708	.0617	.0814	.0835	.1240	.1880	.1803	.1775	.1564	.1287	.1130	.0662	0.1189	0.1820

[1] No observations.
[2] Record not complete and in part estimated.

Another method, which was practiced in compiling the records at Fremont for a number of years, is to compute the saturation deficit directly from each psychrometer reading, using vapor pressure and saturation pressure tables, or a special table in which the saturation deficits are shown directly. This method, however, is probably less precise than the one described above, and gives very different results, because the saturation deficit varies much more widely with changes in temperature than does the vapor pressure. Hence this method is not to be recommended where dependence must be placed on single daily observations at a fixed hour.

The saturation deficit data for the control station up to September, 1918, are given in Table 19.

It will, perhaps, be of interest to note that during the winter months the saturation deficits are of about the same magnitude as vapor pressures for the control station (Table 14) and indicate a relative humidity of about 50 per cent. From April onward, through the growing season, vapor deficits are scarcely more than two-thirds of the magnitude of vapor pressures and indicate relative humidities nearer to 60 per cent. This general change results from the cessation of the strong mountain and anticyclonic winds.

At Wagon Wheel Gap (W–A1) the winter deficits are always of less magnitude than vapor pressures, probably because of the lack of any direct mountain-breeze effects. They are also of less magnitude at all other times, except in May and June, when the relative humidity is 40 or 45 per cent. Thus the dependence of vapor deficits on temperatures as well as on vapor pressures is clearly brought out.

EVAPORATION.

Evaporation observations were begun at the control station and at several other local stations as early as July, 1914. The instrument then in use was the Piche, as modified by the United States Weather Bureau [5] fitted with 10-centimeter glass plates and with 9-centimeter filter papers [6] as a standard. Great difficulty is always experienced in operating these instruments on a basis of daily observations, because of the necessity for frequent adjustments, according to temperature and dryness, to prevent overflowing or drying of the papers. As the capacity of these instruments—40 cubic centimeters—was found to be insufficient for a day's evaporation at midsummer, extra fillings were immediately necessary, and smaller papers were soon adopted. The results were corrected to the standard papers on the basis of the exposed areas of the two kinds.

These observations, unsatisfactory as they seemed at the time, were continued through 1914 and again taken up in April, 1915. During the colder part of this period, to prevent injury to the glass vessels from freezing, various mixtures of alcohol and water were used. It is evident that the alcohol would accelerate losses, and it is equally evident that evaporation of the alcohol would continue freely at temperatures below 32°. Hence this expedient was in nowise satisfactory, even though the mixtures were compared with distilled water to determine relative evaporation rates at temperatures above freezing.

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[5] While the modified Piche evaporimeter was employed by the Weather Bureau for a time in comparisons with other instruments, its indications have always been regarded as most untrustworthy.

[6] Schleicher & Shull's No. 595.

An effort on the part of the writer to overcome the difficulties due to the small capacity and fragility of the container, by substituting a larger metal container for the glass tubes, was also unsuccessful, although this instrument was used for several months in 1915 at the control station. The experiment showed at least that the volumetric method with evaporimeters could never be satisfactory for year long observations, because of the very great changes in volume at the freezing point, and for that matter with every change of temperature. Often these volume changes were sufficient entirely to obscure the water loss for a period of several days in cold weather.

As a result of this experience, four types of wick evaporimeters have been devised and tested, in which evaporation losses were determined by weighing. Type 4 has proved so satisfactory under all conditions that an effort has been made to determine the evaporation rates for all stations by means of this instrument. Types 2 and 4 have been described by the present writer (*5*) as have also the fundamental principles on which they are based. Type 2 was put in service in April, 1916, and gave fairly satisfactory records at several stations during that year. It was an objectionable feature of this type that rain and snow were not entirely excluded from the water chamber, although in the so-called "shade" instrument of each pair this was partly accomplished. The records of this instrument are, therefore, preferred to those of the "sun" instrument, which might absorb the precipitation of an area about one-twentieth as great as the exposed wick. The several instruments in use in 1916 were never standardized, but this objection was in part overcome by rotation among the several stations.

The usable evaporation record, then, begins with 1916, and a large part of it has been secured during the years 1919, 1920, and 1921. At one station (F–13), however, where types 2 and 4 were not used for a whole year, it seems advisable to complete the record for 12 months by reference to the data obtained by the use of type 1 instruments. This type will not be described, except to say that its evaporation surface was a cotton wick, fully exposed to the air and sun, in a horizontal plane. Like the Piche and Livingston instruments, it gave relatively too high values for high wind velocities.

Evaporation at the control station.—The evaporation values obtained with instruments of type 2 in 1916 and of type 4 in 1917 to 1921 are not closely comparable because of differences in shape and in the size of the evaporating areas. They are given together in Table 20, however, because the comparative data for two stations are in part dependent on this 1916 record from the type 2 instrument.

Although the evaporation record of Type 4 instruments has been secured only for parts of four years, and the averages by decades and months can not be considered even as close approximations to "normals," still this record is considered very valuable in several respects, viz:

(1) It shows the magnitude of the evaporation factor during the winter months, due primarily to the somewhat warm and dry character of the descending anticyclonic winds. As already suggested, these winds give the Pikes Peak region a peculiar character, and an examination of the other evaporation records shows that no other region studied has winter conditions so severe.

TABLE 20.—*Actual evaporation at the control station.*

Year.	Decade.	Total evaporation in grams per 100 square centimeters surface.												Total year.	Total growing season.
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
1916	1	.....	.....	.....	[1] 52.9	153.0	101.5	138.5	114.5	135.1	109.4	73.4	67.3	.....	.....
	2	.....	.....	.....	75.5	32.7	113.0	68.8	65.6	82.9	51.2	30.0	76.3	.....	.....
	3	.....	.....	.....	52.6	208.9	205.5	84.0	76.1	113.9	86.0	70.2	62.2	.....	.....
	Month.	.....	.....	.....	181.0	394.6	420.0	291.3	256.2	331.9	246.6	173.6	205.8	.....	1,102.6
1917	1	[2] 39.3	39.4	27.7	54.4	24.2	158.8	169.8	199.8	100.4	117.2	68.7	38.7	.....	.....
	2	24.1	22.6	33.5	46.1	75.9	178.2	207.8	55.3	75.6	122.9	36.5	54.8	.....	.....
	3	49.4	48.6	69.5	59.7	35.4	274.4	280.2	119.0	111.6	106.4	[3] 66.2	62.1	.....	.....
	Month.	112.8	110.6	130.7	160.2	135.5	611.4	657.8	374.1	287.6	346.5	171.4	155.6	3,254.2	1,743.7
1918	1	[4] 41.5	68.4	110.0	32.6	102.0	114.4	101.1	106.6	47.4	.....	.....	.....	.....	.....
	2	10.0	53.9	131.1	27.3	120.8	154.1	86.8	96.9	70.9	.....	.....	.....	.....	.....
	3	41.4	101.2	74.6	67.3	146.9	145.8	129.0	139.3	.....	.....	.....	.....	.....	.....
	Month.	92.9	223.5	315.7	127.2	369.7	414.3	316.9	342.8	.....	.....	.....	.....	.....	1,121.4
1919	1	.....	.....	.....	.....	46.5	62.8	114.0	139.2	103.2	52.5	54.1	58.5	.....	.....
	2	.....	.....	.....	.....	82.2	126.3	156.6	147.6	57.2	50.4	48.3	43.7	.....	.....
	3	.....	.....	.....	.....	95.9	146.3	146.2	148.4	95.6	77.8	36.4	68.3	.....	.....
	Month.	.....	.....	.....	.....	224.6	335.4	416.8	435.2	256.0	180.7	138.8	170.5	.....	1,290.6
1920	1	15.1	28.9	26.6	62.1	78.1	100.1	107.2	75.7	58.1	123.6	30.0	45.6	.....	.....
	2	108.6	35.0	64.4	49.3	54.4	88.6	109.0	74.7	123.6	88.9	38.9	28.9	.....	.....
	3	59.5	27.8	70.9	45.6	120.9	98.2	137.8	108.0	121.8	38.6	41.5	40.8	.....	.....
	Month.	183.2	91.7	161.9	157.0	253.4	286.9	354.0	258.4	303.5	251.1	110.4	115.3	2,526.8	957.4
1921	1	58.3	25.3	57.2	56.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	1	84.1	39.9	88.8	53.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	27.7	60.9	47.9	72.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Month.	170.1	126.1	193.9	181.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average to Apr. 30, 1921 (type 4 only)	1	38.6	40.5	55.4	51.3	62.7	109.0	123.0	130.3	77.3	97.8	50.9	47.6	.....	.....
	2	56.7	37.8	79.4	43.9	83.3	136.8	140.0	93.6	81.8	87.4	41.2	42.5	.....	.....
	3	44.5	59.6	65.7	61.2	99.8	166.2	173.3	128.7	109.7	74.3	48.0	57.1	.....	.....
	Month.	139.8	137.9	200.5	156.4	245.8	412.0	436.3	352.6	268.8	259.5	140.1	147.2	2,896.9	1,278.2

[1] Type 2 wick, "shade" only.
[2] Type 4, "sun" only.
[3] Type 4, "shade" only ("sun" instrument out of order).
[4] Average of two "sun" instruments, standardized, most of time after Jan. 1, 1918.

(Type 2, 1916, 189 square centimeters, in cylinders; type 4, 1917–1921, 100 square centimeters, horizontally.)

(2) It indicates the marked differences that are possible between succeeding years and between growing seasons, the latter explaining far more completely than the records of precipitation do, the variations in growth rates of trees from year to year. The growing seasons of 1917 and 1920 are especially to be contrasted.

(3) It gives a basis on which, in the absence of a long-term record, the evaporation may be computed for other years, in order to show more clearly the cyclic character of growing conditions.

If the indicated annual evaporation is reduced to depths, a figure of 28.96 centimeters or 11.4 inches, is found to be the approximate yearly loss. As the normal precipitation is 21.1 inches, the evaporation represents 54 per cent of the precipitation. At a corresponding elevation at Wagon Wheel Gap, streamflow measurements indicate that about 74 per cent of the total precipitation escapes as evaporation from snow, soil, and vegetation. For the 20 months of observation, the measured evaporation is only 25.9 centimeters per year, or only about 47 per cent of the normal precipitation when entirely unaffected by trees. The instrumental measurements, therefore, are evidently conservative. Evaporation records from open pans usually show more evaporation than precipitation in arid climates.

Evaporation record extended by formula.—In a general way the rate of evaporation from any type of evaporimeter or vessel of water is determined by the capacity of the atmosphere for additional vapor, which affects the rate of diffusion from the evaporating surface, and by the rate of wind movement, which not only assists diffusion but may be the principal source of heat for continuing evaporation. If the evaporating surface is well heated by sunshine, however, it may be warmer than the air; the wind will then be not a source of heat but a means for loss. As evaporation is further complicated by other factors, precise formulæ for computing it, even from free-water surfaces, have never been devised. However, for approximate purposes in this study, to obtain a better idea of the relative evaporation for different years, it seems advisable to determine the ratio between the actual evaporation of Type 4 instruments during 1917 and 1918 and the evaporation which may be computed from the wind, humidity, and sunshine data combined in a manner to give the most consistent results. The coefficient so obtained will then be applied to the corresponding atmospheric conditions for other years, to elaborate the evaporation record for the control station.

Admittedly, because the sunshine record does not indicate the intensity of sunlight as determined by its angle of incidence on a horizontal surface, the coefficient should vary according to the elevation of the sun. It has been considered sufficient to calculate C for each month, assuming that the variable atmospheric conditions affecting intensity would probably be fairly well compensated in the records of twenty months.

The formula used, after three other trials, to compute the coefficient for each decade of the 20 months is as follows:

$$C = \frac{E}{(W + VD)\, SS}$$

in which E is the evaporation in cubic centimeters, W the wind movement in total miles for the same period, VD the sum of the daily saturation deficits, in inches, times 1,000; and SS the average minutes of sunshine per day, divided by 10,000.

Conversely, to calculate the rate of evaporation when C has been determined—

$$E = C \times SS(W + VD).$$

As these data are lacking in precise value, it is necessary only to state that the coefficients vary widely for corresponding periods of the year, and that on the average they vary, according to the sun's elevation and other factors, from 0.477 in January to 1.336 in July.

The evaporation computed by decades for all periods of record from March, 1910, to December, 1916, is summarized in Tables 21 and 22, with the actual record since January, 1917. (See fig. 4.)

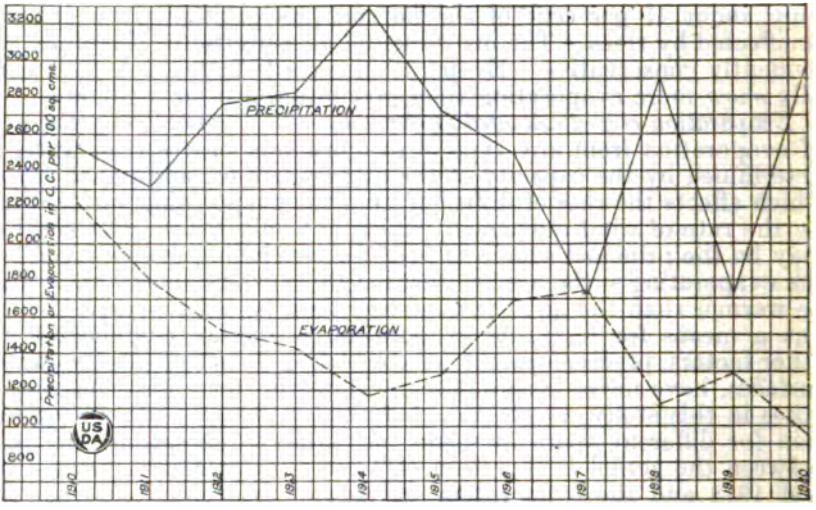

FIG. 4.—Variations in the relation between precipitation and evaporation for growing seasons. Control station.

The principal value of Table 21 is that it shows the maximum evaporation that may occur during the winter, the maximum rates at this time being those which may cause injury to trees. On the whole, however, this has little advantage over Table 20, for it is seen that the maxima during the winter do not go to such great extremes, relative to average rates, as, for example, they do during June.

On the other hand, Table 22 brings out certain facts which can not be reached from a consideration of any single climatic condition. In the evaporation data alone it is seen that the variations as between years and growing seasons are much greater than might be expected from a consideration of air temperatures or wind movements, and that saturation deficits (Table 19) are not always fully reflected in the evaporation quantities. In a general way, when precipitation and atmospheric humidity are high, evaporation is low, and vice versa; but as there are some exceptions to this rule, to measure the moisture conditions it is really necessary to establish the ratio between water supply (precipitation) and water loss (evaporation).

TABLE 21.—*Maximum probable evaporation rates as indicated by computed values, March, 1910, to December, 1916; actual evaporation, January, 1917, to April, 1921.*

Decade.	Total evaporation per decade. [Cubic centimeters per 100 square centimeters horizontal surface.]												Year.	Growing season.
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
1	76.9	74.9	110.0	120.3	203.0	346.4	284.5	199.8	237.7	144.8	82.6	58.5	.....	.....
2	108.6	54.4	131.1	95.6	209.0	291.0	274.9	147.6	129.5	133.5	61.3	54.8	.....	.....
3	61.7	101.2	97.8	88.3	291.3	316.3	280.2	215.0	121.8	153.0	66.2	68.3	.....	.....
Month.	199.6	223.5	315.7	298.7	564.3	802.8	826.9	433.7	448.8	358.9	196.1	170.5	4,062.8	2,232.3

TABLE 22.—*Variations in annual and growing-season evaporation and their relation to precipitation.*

[Amounts for an area of 100 square centimeters. Evaporation computed by formula prior to 1917.]

Year.	Annual evaporation.		Precipitation for corresponding year.		Growing-season evaporation.		Growing-season precipitation.	
	Amount.	Variation from average.	Amount.	Ratio to evaporation.	Amount.	Variation from Average.	Amount.	Ratio to evaporation.
	C. c.	*Per cent.*	*C. c.*		*C. c.*	*Per cent.*	*C. c.*	
1910	[1] 4,063	+27	4,704	1.16	2,232	+51	2,530	1.13
1911	3,837	+20	5,002	1.30	1,804	+22	2,315	1.28
1912	3,446	+8	4,990	1.45	1,528	+3	2,763	1.81
1913	2,806	−12	6,740	2.40	1,433	−3	2,828	1.97
1914	[2] 2,934	−8	6,322	2.15	1,174	−21	3,291	2.80
1915	[2] 2,801	−12	5,718	2.04	1,284	−13	2,729	2.12
1916	3,657	+14	4,990	1.36	1,694	+15	2,492	1.47
1917	3,254	+2	4,374	1.34	1,744	+18	1,703	0.98
1918	[4] 3,106	−3	4,995	1.61	1,121	−24	2,902	2.59
1919	[5] 2,752	−14	3,771	1.37	1,291	−13	1,734	1.34
1920	2,527	−21	5,406	2.14	957	−35	2,982	3.12
Average	3,198	±13	5,183	[6] 1.665	1,478	±20	2,570	[7] 1.874

[1] Year from March, 1910, to February, 1911.
[2] Assuming missing periods, January to March, to have been "normal."
[3] Year from March, 1915, to February, 1916.
[4] Year from September 21, 1917, to September 20, 1918.
[5] Year from May, 1919, to April, 1920.
[6] ± 0.100.
[7] ± 0.157.

In point of actual evaporation and relative shortage of precipitation, the year 1910 has probably been the most severe our records have known, followed by 1911, both years having unusually high temperatures and much sunshine. The whole year 1917, with moderate evaporation and lowest precipitation (excepting 1919), was only moderately severe. The year 1913, which was especially deficient in sunshine, seems to have presented the most abundant surplus of moisture.

One may turn with more interest to the growing-season data, and also with more confidence, because here both extremes are found within the period of actual evaporation measurements, and also because no shifting of the period limits is necessary. Here it is seen that the lowest evaporation, that for 1920, is less than 45 per cent of that for 1910, and that the most severe growing season (1917), as shown by the ratio of precipitation to evaporation, is not one in which the evaporation was itself excessive. Although these years are only partly covered by soil-moisture records, it should be noted that the exhaustion of soil moisture was in 1917 more complete than in any other year of which there is knowledge.

On the other hand, it should not be construed that the low evaporation and relatively great precipitation of 1920 constituted particularly favorable growing conditions. The size of rings formed has

not been determined, but other evidence points to a very serious deficiency in the growth activity, with a resultant lack of vigor in the new growth of 1921, notwithstanding an unusual abundance of water in 1921.

It would seem that for the region and flora that are being described, an increasing ratio of precipitation to evaporation might be considered favorable until the ratio reaches about 2:1, after which any increase is probably detrimental. This should be definitely determined by a study of the width and structure of rings.

A succession of years such as 1916 and 1917 is evidently a very serious strain on the forest, and probably this period has done more toward weeding out mature trees in the Pikes Peak region than any other set of conditions covered by this series of observations. This has been particularly noted in relation to yellow pine, both in pure stands and where the tree competes with Douglas fir. The yellow pine suffered more than any other species from the unusual drying winds of January and March, 1916. Further weakening through two seasons of drought no doubt gave its natural enemy, the mistletoe, a very decided advantage, and the attacks of this parasite became most evident in 1920 in a very marked deterioration of old trees, wherever mistletoe was at all abundant. As elsewhere pointed out, this loss of yellow pine is giving Douglas fir in many places a decided advantage. These casually observed facts are stated in order to show the importance of unusual conditions in the life of the forest, and the danger arising from short-period comparisons of the conditions in the several forest types. Without doubt this comparison of years, which has been attempted, demands as much consideration in drawing conclusions as any direct comparison of conditions in various forests which it is possible to make.

Relative evaporation rates at other stations.—Prior to 1916 the efforts to measure evaporation continuously were largely unsuccessful, and during 1916 satisfactory instruments were available for only a few stations. In 1917 practically the same line-up was secured with the latest type of instruments. After this trial the number of instruments was greatly increased, and more satisfactory records were secured through calibration of the instruments and through their frequent shifting from one station to another. From March to the cessation of observations in September, 1918, all the local stations were covered, with systematic rotation of instruments among them; hence this portion of the record is very satisfactory. The record was further rounded out from May, 1919, to September, 1920, a special effort being made to cover the winter period at all stations.

As there are no long records for any of the stations that were secured with a single type of instrument, it has seemed best to express the evaporation at an outlying station as a percentage of that for the control station, for each month of record, regardless of the type of instrument currently in use. When, however, the same month has been covered during more than one year, the arithmetic means for the control station and the outlying station have been similarly compared. The ratios for years and growing seasons are based on the mean total amounts of evaporation for the respective periods.

In Table 23 the comparative evaporation rates, so far as any approximate basis will permit, are shown.

TABLE 23.—*Comparative evaporation.*

[Ratios to Station F-1; Type 4 evaporimeters unless otherwise specified.]

Station No.	Type.	Locality.	Height above ground.	Period.	Number months record.	Month.												Annual.[1]	Growing season.[1]
						Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
						Mean total evaporation, in cubic centimeters.													
			Feet.																
F-1.....	Control.....	Pikes Peak.	20	Jan., 1917 to Apr., 1921.	45	140	138	200	156	246	412	436	353	269	260	140	147	2,897	1,278
						Comparative evaporation, ratios to F-1.													
H-2....	Sandhills.....	Nebraska..	6	May, 1919 to Apr., 1921.	24	0.25	0.57	0.73	0.92	0.81	0.89	0.88	0.88	0.75	0.55	0.36	0.24	0.713	0.888
M-1....	Western yellow pine.	Pikes Peak.	5	Feb., 1917 to Apr., 1921.	44	1.02	1.12	1.30	1.26	1.40	1.14	1.12	1.39	1.56	1.20	.89	.99	1.217	1.243
F-2G...	.....do.....	.....do.....	1	Mar., 1918 to Apr., 1920.	19	.67	.88	.79	.76	.95	.87	.81	.86	.95	.81	.64	.79	.795	.852
F-12....	.....do.....	.....do.....	1	Mar., 1918 to Feb., 1920.	17	.58	.80	.73	.83	1.07	.97	.97	.93	.86	.71	.54	.54	.841	.950
F-4.....	Pine-fir.....	.....do.....	1	Mar., 1918 to Sept. 1920.	24	.31	.42	.49	.71	.61	.70	.76	.65	.83	.54	.30	.34	.602	.724
F-7-8...	Douglas fir, clear cut.	.....do.....	1	Jan., 1917 to Apr., 1920.	32	.41	.40	.52	.70	.92	.85	.81	.85	.82	.62	.44	.28	.704	.841
F-14....	Douglas fir, half cut.	.....do.....	1	Jan., 1918 to Apr., 1920.	20	.18	.23	.34	.57	.70	.65	.57	.71	.60	.47	.30	.09	.512	.641
F-15....	.....do.....	.....do.....	1	Jan., 1918 to Feb., 1920.	20	.17	.22	.22	.36	.65	.70	.57	.62	.56	.43	.23	.07	.470	.623
F-9.....	Douglas fir, uncut.	.....do.....	1	Jan., 1917 to Apr., 1920.	32	.14	.17	.14	.30	.38	.36	.30	.39	.29	.24	.27	.21	.292	.345
W-A1[2].	Douglas fir, north.	Rio Grande	5	Aug., 1919 to Mar., 1921.	20	.08	.14	.33	.69	.78	1.20	1.02	.93	.56	.49	.18	.05	.648	1.016
W-B2..	South slope, clear cut.	.....do.....	5	Aug., 1919 to Mar., 1921.	20	.31	.66	.65	.97	1.68	1.80	1.37	1.20	1.13	.94	.73	.37	1.104	1.423
F-6.....	Limber pine..	Pikes Peak.	1	Mar., 1918 to Sept., 1920.	24	.50	.49	.46	.64	.69	.71	.57	.66	.66	.48	.54	.56	.599	.642
F-13[2]..	.....do.....	...do.....	5	Sept., 1915 to Sept. 1916.	11	1.94	.....	.....	1.12	1.22	1.32	1.56	1.08	1.17	1.38	1.26	.91	1.258	1.318
F-11....	Lodgepole pine	Southern Wyoming	5	Jan., 1917 to Sept., 1918.	[illegible]20	.16	.11	.23	.80	.64	.77	.75	.77	.92	.67	.60	.31	.638	.767
F-3G...	Engelmann spruce.	Pikes Peak.	1	Mar. 1918 to Apr., 1920.	17	.07	.04	.15	.26	.39	.48	.36	.32	.36	.22	.15	.05	.281	.348
F-5.....	.....do.....	.....do.....	1	Mar., 1918 to Sept., 1920.	24	.26	.30	.28	.28	.36	.35	.29	.35	.39	.38	.25	.17	.317	.343
F-16[4]..	Timberline....	.....do.....	10	Oct., 1916 to Aug., 1918.	23	.17	.10	.20	.40	.72	.62	.67	1.09	1.72	1.22	1.01	.30	.773	.843
W-D...	High spruce, burn.	Rio Grande	5	Nov. 1919 to Mar., 1921.	17	.46	.74	.52	.52	1.08	1.37	1.54	1.18	1.50	1.18	.49	.41	1.048	1.430

[1] Annual and growing-season mean ratios are algebraic, total quantities being compared with totals for control station in same period.

[2] Value for July estimated from other records obtained near by.

[3] Type 1 September to January; type 2 April to September.

[4] Type 2 in 1916; type 4 later.

Table 23 contains a number of surprises and brings out certain relationships of the types and localities studied, the knowledge of which could hardly have been obtained through the examination of the several conditions affecting evaporation—sunshine, humidity, wind, and temperature. The desirability of a direct measure of evaporation is therefore apparent, and the importance of a method which gives the most probable weight to each of the component factors in evaporation must not be minimized.

One of the first points to be noted is that, with the exception of one or two of the very open situations, the winter ratios for the outlying stations are much lower than the summer ratios to the control station. This is partly due to the effect of cover and to the fact that there is some slope, which may cut off insolation much more completely in winter than in summer. A still more important point is that when the air temperatures are below freezing there can be practically no evaporation without sunlight to thaw the instrument (or, for that matter, the leaf), but, when the air is everywhere warm, insolation is by no means so important a factor. It is well to bear in mind that under very arid conditions shading is by no means a preventive of water losses.

The following observations may be made with regard to conditions of the several forest types:

(1) It is readily seen that, of the yellow pine sites examined, the most severe is by no means the planting site in the Nebraska sandhills, but is found at the foot of the Pikes Peak region (M–1), where the low humidity of the mountains is combined with the relatively high temperatures of the low elevations. The ratio for Station M–1 is uniformly high throughout the year, the depression in November and December not being accounted for by any of the factors which have been more extensively studied. On the other hand, because of the low wind movement and higher humidity, the Nebraska sandhills present a far less severe condition, except during the summer when the temperature contrast is greatest. It is possibly of some significance that the highest relative rate occurs here about September 1. Of the several yellow pine sites examined, that which approaches a condition favorable for Douglas fir (F–4) is seen to be most moderate in its evaporation stresses. The low values denote the influence of shade more than anything else.

(2) The contrast between open and shaded Douglas fir sites is brought out very clearly. Thus the four local north-slope stations show a marked grading down from the clear-cut to the virgin stand, the latter, for the year as a whole, having only two-fifths the evaporation rate of the former. Whether or not the high evaporation rate in the open area is a prohibitive factor for any of the species, there is presented, at a single glance, a striking picture of the changed conditions for reproductiion which necessarily follow cutting of the parent forest. Again, in this group a surprise is met with in the high evaporation rate for the Wagon Wheel Gap stations, where, as already shown, the temperatures and wind movements are generally lower than at Fremont, and the vapor pressures markedly lower. Thus at Station W–A1, which probably receives less than half the direct insolation received at the control station, evaporation goes appreciably higher during the early part of the summer but dwindles almost to nothing in the coldest winter months. Where atmospheric

dryness plays such an important part, the contrast between a shaded north-slope site and an open south exposure is far less marked than at Fremont, except for the coldest part of the year.

(3) The high spruce burn at Wagon Wheel Gap (W–D) shows, for the growing season, the highest ratio to the control station of all the stations studied. During the winter months its ratios are relatively much higher than those for the timberline station on Pikes Peak, due no doubt to the fact that the latter receives negligible insolation. It has already been noted that Station W–D shows at all times somewhat greater wind movement than the control station. The importance of this factor, combined with full insolation and acting in the presence of low air temperatures, is plainly shown in the not insignificant evaporation of the winter period.

The very low evaporation rates in the two local spruce stands (F–3 and F–5) reflect the influence both of heavy shade and of the close growth of the stand which reduces the air movement almost to nothing. Here again, however, the potent effect of atmospheric humidity may be observed; for, although the insolation at either station is probably not more than 10 per cent of that received at the control station and the wind velocity is reduced in almost as great proportion, the evaporation is about three-tenths as great as at the control station. It should be noted that at Station F–3, as at the north-slope fir stations, the evaporimeter is sometimes completely covered by snow. This does not occur at Station F–5.

(4) The single lodgepole pine station (F–11) is marked by moderate evaporation at all periods. The winter rate is not excessively low, as the temperatures might suggest, because the wind is at this time a very strong factor.

(5) The local limber pine type (F–6) shows clearly the effects of winter winds which strike the slope very squarely, the winter evaporation rates being among the highest notwithstanding the lack of sunlight on this northwest slope. The higher limber pine site (F–13), which has been depicted as presenting nearly timberline conditions, is, so far as the available record can be depended upon, even more severe in winter than is the actual timberline site, the former being considerably warmer and better insolated.

(6) If the three major types are compared, for which the data are adequate, it is seen that, with anything like normal cover, there is a decided tendency for the evaporation rate to grade down from pine to Douglas fir and from the latter to spruce. This decrease accompanies the decreasing temperatures which are characteristic of the types. It is undoubtedly augmented by the reduction of insolation due to increasingly dense stands in the higher zones. Although free air movement evidently increases generally with increase in elevation, the greater density of the stands tends to nullify any effect from this source.

It may, then, safely be said that the typical conditions for the reproduction of the species are evidently less severe, as regards the tendency toward evaporation, in the spruce than in the fir or pine types. This statement is not in the least weakened by the fact that in very open situations there is practically as much evaporation in one zone as in another, as is evidenced by comparing Station M–1 with the control station, or Station W–B2 with Station W–D. It

is known that in these very open situations the reproduction is never abundant and often is not typical of the climax forest. In the Pikes Peak region there is a strong tendency for limber pine to invade every open site; in the Wagon Wheel Gap region bristlecone pine is the pioneer.

Although, then, it may be seriously questioned whether the evaporation stress is the controlling or limiting condition in many instances, still there can be little doubt that this measurement, sensitive as it is to every atmospheric condition, gives an extremely convenient and valuable index to site conditions, and particularly as it reflects in a simple term the general temperature and sunlight conditions.

The evaporation measure seems particularly useful in expressing the broader differences between regions. Thus, only a confused picture of the Nebraska sandhills is obtained by determining that the temperatures are higher, the humidity higher, the wind movement lower, and the sunshine (this is said for illustrative purposes only) less than at the control station. Orientation is, however, immediately possible when it is found that all these differences are algebraically summed up in less evaporation in Nebraska. When this result is considered in connection with each of the individual factors, the phenomena of tree growth become very clear.

On the other hand, the high evaporation rates which are found at the Wagon Wheel Gap stations, in comparison with the control station, demand an explanation. If the evaporation rate has any direct bearing on the choice of species, how is it that unity evaporation gives essentially the same result in the one locality (compare Stations F–9 and W–A1) as three units of growing-season evaporation in the other? It should be noted that even the highest rate recorded in these data is probably not excessive for established vegetation; with a reasonable water supply, the highest rate may, possibly, represent the most favorable and not the least favorable growing conditions. As the high rate in the Wagon Wheel Gap locality is induced primarily by a dry atmosphere, which represents a normal condition, it seems probable that that region is not, in the long run, subject to any more extreme maxima than the Pikes Peak region, where sunshine, humidity, and temperatures suffer greater fluctuations from year to year. This can be certainly determined only by much longer study.

It seems, therefore, that, if evaporation rates bear directly on the composition of forest types, this can be determined in only two ways. It may be determined by a more intensive study of evaporation rates as they affect young seedlings, in close correlation with the determination of the moisture supplies of those seedlings. This points to the same situation that has been reached in the study of air temperatures and soil temperatures, namely that the conditions which must be critical in the early establishment of forest trees are special, perhaps short-term, conditions, and are not covered by these general comparisons.

On the other hand, if evaporation is measured as in these tests but through a longer term of years, it is probable that extreme conditions in the various forest types, particularly for the more widely separated localities, will be brought to light, which, although not necessarily constituting criteria of the resistance of the species, will give a better conception of the relative stresses which each species

is compelled to tolerate before it can come fully into possession of the site. To attempt now to compare the extreme conditions in the various types on the basis of records for only two or three growing seasons, does not promise fruitful results. Even the somewhat serious drought conditions presented in the late growing season of 1917 can not be used in this manner, as there were at that time only a few evaporimeters in operation, and no special observations on the mortality of seedlings were made. It is probable that the soil-moisture conditions to be discussed later, are more significant in this connection than any evaporation rates could possibly be.

There is, however, in the whole region under discussion an annual drought which is absolute, and which results from the freezing of the soil. As the duration of this freezing is so different in the different forest types, it has always seemed probable that this drought period might have a very direct bearing on seedling establishment. It may be said at this point that a consideration of the possibilities of winter drying does not materially alter the conception of the relative positions of the types, except in showing that typical warm yellow pine sites are least liable to winter drying. On the other hand, the evaporation at this season still further emphasizes the severity of any strictly open site. The high evaporation rate which seems characteristic of the Rio Grande region does not seem to be at all compensated for by a warmer soil; in fact, the period of freezing there is a little longer than at Fremont.

It has seemed desirable to discuss this evaporation problem somewhat carefully, and to accept the comparative data cautiously, because of the dual rôle which evaporation plays, or, to be more specific, because of the double function of the evaporation rate as a measure of growing conditions. It is evident that loss of water by the plant is rarely, if ever, advantageous per se, yet that it is inevitable if the plant is to enjoy the benefits of light and is to be able to absorb carbon dioxide. A good rate of evaporation in the growing season may, therefore, indicate the optimum growing conditions, in other respects, for the more light-demanding and heat-demanding of the plants. Likewise, a relatively lower rate is likely to accompany the light and temperature conditions which are best for the less demanding or more "tolerant" plants. Therefore, although there may be little hesitancy in declaring the facts as to evaporation to be so and so with respect to the several forest types, there is hesitation about saying that these facts indicate anything as to the ability of the species to withstand evaporation or to balance it with equal intake. This, of course, is the point on which information is most needed, that of the drought-resisting relations.

It is greatly to be regretted that, because of their use of a different atmometer, comparison can not be made with the evaporation records of Pearson (*19*), Shreve (*21*), Weaver (*23*), and others. A broader comparison would be valuable in indicating the importance or the probable lack of importance of absolute evaporation rates. It is to be noted, however, that the results obtained by these investigators are uniformly in agreement with the results described in this paper, namely, that the evaporation rate is always highest in the more open situations and in the most xerophytic plant types. Further, those authors lay considerable stress on the probability that high evaporation directly drives out the more mesophytic plants.

SOIL TEMPERATURES.

Before the initiation of this project it had been observed that the surface temperature of sandy soils in Nebraska might be high enough at midday to injure young planted trees of yellow pine and jack pine and that they apparently had the effect of drying the lightly protected stems just at the root collar. It was also thought, after observation of the vegetational difference between north and south exposures in the Rocky Mountain region, that soil temperatures might express more fully than any other measure the cause of this difference, which results primarily from the amounts of insolation received. In the preliminary report (*3*) on this project, soil temperatures were considered only as climatic elements expressing the possible length of the growing seasons. There is still much doubt among ecologists as to whether these temperatures have the greater significance in connection with climatic or with soil conditions; but it is now evident that a complete separation of the two sets of conditions is out of the question, and that soil temperatures form an important link between them. That they have been looked upon as results of rather than features of the weather conditions is indicated by the fact that the Weather Bureau has never recorded soil temperatures on an extensive scale except in connection with a few special studies, such as the study of streamflow now being conducted at Wagon Wheel Gap, Colo.

The factors influencing soil temperatures, at a given time and place, have been investigated, notably by Bouyoucos (*7*). The Wyoming Agricultural Experiment Station has for a few years recorded soil temperatures at Laramie. A great many other records have no doubt been obtained, but nothing comparable to the great organized mass of air temperature records. During the last four years the Ecological Society of America has lent its influence to the organization of a more or less complete soil-temperature survey of the United States; and as a great many competent observers have thus become interested in the subject it is to be hoped that comparable data will soon be available for different regions.

Pearson (*17*), in his study of the yellow-pine forest and parks, made comparative observations for only four months, July to October, during which time, at a depth of 2 feet, he found the forest soil to be 5.1 degrees cooler than the open park. In February, 1913, he also made some examinations which are of interest here. The day was warm, and all snow had been melted by the direct and reflected light on the south side of a pine tree, while on the north side, and in an opening, the snow cover was from 6 to 8 inches deep. In the first position there was no trace of frost in the soil; in the second it extended down 13½ inches, and in the open park 23 inches. This single observation, whose general import is indicated by data to be presented, is of principal interest in showing the conditions which young seedlings must contend with before the forest is established; for Pearson (*16*) has also shown that seedlings in the pine type are compelled by summer heat and drought to adhere very closely to the shaded spots. In a later report Pearson (*19*) has given more complete data for all of the forest types, and these will later be compared with the data of the present investigation.

Shreve (*21*), in his study of mountain vegetation, has given only slight attention to soil temperatures. The few records of minima which were obtained seem to have no bearing on the present study.

Larsen (*13*), in his companion report on the types of Idaho and vicinity, gives the results of systematic soil-temperature observations, at depths of ½, 1, and 2 feet, extending over a period of several years. One of the most interesting features of these data is that the soil of the white pine type, in the vicinity of the Priest River Forest Experiment Station, which occupies a northeast slope that is almost without insolation for several months, barely freezes to a depth of one foot. This is apparently due to the fact that early snows are retained, the winter blanket becomes very heavy, and radiation is so checked that much of the summer heat is retained. (See Bouyoucos (*8*).)

It will be shown that lodgepole pine, in its optimum environment, is similarly protected. It appears to be of great significance that western white pine, perhaps the nearest relative of any of the eastern conifers attaining a good development in the Rocky Mountain region, does so under very low atmospheric temperatures, but with the resultant protection of a high relative humidity, and with its moisture supply probably never completely cut off by the freezing of the soil. A southwest slope, also in the vicinity of the Priest River Forest Experiment Station, shows about the same soil minimum at 12 inches; but its mean temperature for the whole "rest period" is 3.3° F. higher than that of the northeast slope, and for the entire year 4.6° higher. In neither place does the soil freeze to a depth of 24 inches. This southwest slope, occupied by western yellow pine and Douglas fir, shows a mean annual temperature at 12 inches depth of 47.9° F., and a January temperature of 34.1°, both of which are 3.1° higher than the corresponding temperatures at Fremont (Station F-2). The midwinter air temperatures, however, are lower in the Idaho region.

Special conditions affecting soil temperatures in this study.—Soil temperatures have been observed at each of the special stations for this study, including Monument and Foxpark, practically during the entire period of the operation of the stations. In addition they have been recorded at each of the meteorological stations at Wagon Wheel Gap, three of which are mentioned in this phase of the study. A few scattered observations taken in connection with other projects will also be called into use. For the most part these were made without any special preparation, that is, a thermometer was simply inserted into a hole of the desired depth and protected from direct air circulation. These observations are mainly for a depth of 12 inches.

Prior to 1914 the three stations under observation at Fremont were equipped with 1 and 2 foot soil thermometers. In 1914 it was decided that the 2-foot depth had no individual significance, and with the installation of several new stations the new ones and the older ones were equipped for readings at 1 and 4 feet. This arrangement has been standard since 1914.

The stations at Wagon Wheel Gap were at first equipped with 1-foot thermometers only. During 1913, 4-foot thermometers were added at all stations then in operation and the standard equipment was placed at stations established in the fall of that year. The 1-foot thermometers have been in wooden tubes a greater part of the time. The Foxpark station had 1 and 2 foot thermometers from 1914 to April, 1916. The 4-foot thermometer was placed when more extensive observations were begun in 1916. Local Station F-13 (limber pine) had only 1 and 2 foot thermometers

during the period of its operation, because of the impenetrable soil encountered below a depth of 2 feet. Little use has been found for the temperature records for a depth of 2 feet, but they will be mentioned where they appear to give additional information of value.

For the most part, soil thermometers have been placed in iron pipes. Standard 1-inch galvanized pipe has always been used, the lower end being sealed either by a threaded cap or by welding. The practical advantages of this arrangement over any other type of tube, or over long-stemmed thermometers which may be read without moving, are obvious—namely, durability, dryness, convenience, and cheapness. In fact, temperatures at a depth of 4 feet can hardly be measured in any other way. The exposed end of the pipe is capped, the suspending cord for the thermometer being sealed to the inside of the cap. The standard Weather Bureau "mercurial thermometer," Fahrenheit scale, with cylindrical bulb, has been used mainly. To prevent any immediate change when the thermometer is raised for reading, the bulb is inserted in a cork or a vial of alcohol. The cork is a good non-conductor and serves as a cushion when the thermometer is placed at the bottom of the pipe. There is no doubt as to the accuracy of the readings at 4 feet when obtained in this way, since, with the bulb protected, no change in the mercury is noted for 20 to 30 seconds, as a general rule, while the reading may be taken in 3 to 5 seconds after removal of the thermometer from its seat.

It is, however, greatly to be regretted that in the soil-temperature observations at a depth of 1 foot iron pipes have been used, since at this depth these introduce an avoidable error into the temperatures recorded. The technical problems encountered in measuring soil temperatures have been discussed in detail in Research Methods (*24*), but for the sake of clarity it is desirable to explain the influence of the iron pipe on the temperature records here presented. The iron pipe is a good conductor of heat, and, especially if the exposed portion becomes insolated, may conduct heat to a depth of 1 foot more rapidly than would the soil itself. Likewise, at night, the pipe may carry away heat to the air which is cooler than the soil. The soil thermometer in an iron pipe, therefore, goes through a greater daily range than the soil itself. For the well-insolated control station, in September, at a depth of 1 foot, the range in the iron pipe was found to be 7.93°, as compared with 3.41° in a wooden tube, in which the temperatures always corresponded closely to those of the soil itself.

It is not admitted, however, that the use of iron pipes has any appreciable influence on temperatures recorded at a depth of 4 feet; in view of the very gradual changes in such temperatures and the absence of appreciable daily oscillations, it is evident that the usual morning observations give a satisfactory basis for calculating mean temperatures. Also, this influence of the iron pipe is probably, in the long run, completely balanced; that is, the mean temperature in the iron pipe would be the same as in the soil proper, because absorption and radiation by the pipe must be just about equal. The pipe would, however, raise the temperatures in spring and summer, and lower them in fall and winter—the general cooling period. Even this is relatively unimportant, compared with its effect on the single daily temperature recorded. The great number of soil-temperature observations in this study have been made between 8 and

10 a.m., and a few as early as 7 a.m. The minimum soil temperature occurs usually several hours later than the minimum air temperature, but for most sites it occurs some time between 8 a.m. and noon. It is, therefore, readily seen that the tendency has been to record, for 1-foot temperatures, the minima rather than the mean temperatures for the days of record. The conductivity of the iron pipe has an influence in making these minima lower than they actually were in the soil, unless the insolation of the current day has proceeded long enough to be felt at the base of the pipe, as, for example, on an easterly exposure.

The mean temperature of the soil of a given site may be almost constantly either higher or lower than the mean air temperature, depending on the amount of insolation received. The air temperature in a large measure reflects the average soil temperature of all the sites in a region of considerable extent. According to Moore (*15*), however, the more or less constant difference between the temperatures of sites in the same locality disappears when great depths are considered. Indeed, it is sometimes said that at a depth of about 50 feet the soil temperature does not change and is, at any time, an accurate index to the mean annual air temperatures above.

At a depth of 4 feet the soil temperatures, although not subject to rapid changes, appear to show in their year-long values the amount and effectiveness of the insolation received locally. It is, therefore, believed that a comparison of the 1-foot and 4-foot temperatures for entire years is the simplest means of determining the probable extent to which the factors mentioned above—that is, the use of iron pipes and the prevalence of morning observations—have tended to give values for the 1-foot depth lower than the true means.

Table 24 shows the probable mean error in the 1-foot soil temperatures as determined by comparison with the 4-foot temperatures for corresponding periods. It must be recognized that the mean corrections so indicated are not equally applicable at all seasons, and may not be absolutely right, even though relatively so for the several stations. It should be noted also that the periods of comparison here considered are not identical with those for which the average temperatures for each station and depth have been computed.

TABLE 24.—*Probable mean error in 1-foot soil temperatures.*

[Determined by comparison with 4-foot temperatures for corresponding periods.]

Station.	Probable depression of temperature in pipe below the mean, at hour of observation.	Station.	Probable depression of temperature in pipe below the mean, at hour of observation.
	° *F.*		° *F.*
F-1	[1] 2.92	F-13	No data.
F-2	1.01	F-14	1.11
F-3	0.71	F-15	0.97
F-4	0.34	F-16	1.38
F-5	1.40	H-2	1.05
F-6	1.17	M-1	0.64
F-7-8	1.10	W-A1	0.38
F-9	0.94	W-A2	[2] 3.16
F-11	1.19	W-D	0.05
F-12	0.78	W-F	0.34

[1] 1916–17 only.

[2] 1914–1917.

All other stations in the Pikes Peak locality should be subject to less error than the control station, both because nearly all are better protected from direct insolation and radiation, and because the observations have been taken at later hours, when, ordinarily, the minimum temperature in the iron pipe will have been passed. Both the time and the amount of insolation, however, are probably important in determining the amount of the depression at the observation hour.

One of the Wagon Wheel Gap stations (WA–1), which has a telethermoscope for its 1-foot temperatures, should have no error in the 9 a. m. readings, but these may be lower than the mean temperatures. The corresponding south-slope station (A–2), although its thermometer has always been in a wooden tube, is subject to full radiation and insolation all the year, but this is not received until late in the day, which probably accounts for the low 1-foot temperatures at 9 a. m. However, in illustration of the variability of this correction with season and time of insolation, it should be mentioned that at midsummer the 9 a. m. temperatures were found to be about 0.9° F. above the daily means, while in the winter they must be several degrees below the means. The data for the high spruce stations should be fairly close to true mean temperatures, because their readings have been taken about midday. As the Foxpark and Monument stations have been regularly visited at 8 a. m. or earlier, practically minimum temperatures in the iron pipes may be expected, except that the Monument station, like Station F–4, may receive insolation very early. The sandhills station (H–2) has had only a wooden tube at its 1-foot depth, and is on a northerly slope, both of which factors would tend toward low corrections.

Seasonal soil temperatures at the control station.—In Tables 25 and 26 are presented the results of soil-temperature observations at the control station, by 10-day periods up to 1918, for the 1, 2, and 4 foot depths. Although considerable data have been added at this and other stations since 1918, it is not felt to be necessary to extend the averages; moreover, the use of such data would further complicate the problem of accounting for the 1-foot depressions as described above, since at a number of the stations wooden tubes have been substituted for iron pipes in this later period.

The following points are noteworthy:

(1) The mean soil temperature for 1 foot is 3.1° higher than the mean air temperature for this station, and 6° higher if the correction indicated by Table 24 is used. For 2 feet it is 5.4° higher and for 4 feet it is 5.7° higher, only corresponding periods being compared.

(2) In the six years that have practically complete records, the 1-foot annual mean temperature shows an average variation from the normal of 1.07°. The first two years of observation were doubtless warmer than any since that time, although 1914 had a very warm growing season, and may have been on the whole as warm as 1911.

(3) The greatest variation between corresponding decades occurs about the 1st of June, when it amounts to an average for nine years of 3.46°. This is on account of the effectiveness of insolation at this time, and because of the fact that in some years the soil may be very dry by June 1; but in other years snows may be occurring at this time.

(4) The least variation in corresponding decades is found at the end of the growing season, the first decade of September showing an

TABLE 25.—*Mean soil temperatures at the control station (F-1)—1 foot.*

Year.	Decade.	January.	February.	March.	April.	May.	June	July.	August.	September.	October.	November.	December.	Mean annual.	Growing season.
1910	1	.....	.....	32.44	39.12	43.02	55.94	58.48	56.91	57.73	52.14	41.29	34.07	.....	.....
	2	.....	28.01	34.65	39.04	44.50	57.88	60.01	56.53	57.91	49.39	38.62	32.83	.....	.....
	3	.....	29.80	40.25	43.42	47.25	60.77	61.11	56.29	52.89	41.52	37.75	28.60	.....	.....
	Month.	(1)	28.90	35.98	40.53	45.00	58.20	59.91	56.57	56.18	47.48	39.22	31.73	43.96	58.16
1911	1	26.38	34.01	32.35	38.34	43.75	56.04	56.33	59.57	53.43	50.05	35.10	30.64	.....	.....
	2	32.12	33.68	34.02	37.42	49.78	56.87	56.45	59.88	55.74	46.78	35.67	28.04	.....	.....
	3	33.59	30.59	35.06	41.09	49.25	57.77	54.88	52.83	55.13	38.79	31.38	27.99	.....	.....
	Month.	30.79	32.92	33.85	38.95	47.65	56.89	55.85	57.28	54.77	45.00	34.05	28.86	43.07	56.40
1912	1	23.29	27.68	28.90	35.20	40.23	49.93	56.23	55.90	57.11	44.79	35.77	30.97	.....	.....
	2	27.08	29.08	31.55	35.75	37.33	45.68	57.39	56.42	52.81	42.74	35.35	29.29	.....	.....
	3	30.08	27.48	32.02	35.11	51.25	50.25	56.79	58.15	43.56	40.19	33.16	23.62	.....	.....
	Month.	26.91	28.10	30.86	35.35	43.20	48.62	56.80	56.86	51.16	42.49	34.76	27.82	40.24	54.38
1913	1	25.61	26.80	29.88	35.72	42.91	50.46	62.49	61.12	56.55	45.41	37.47	33.51	.....	.....
	2	25.53	29.20	31.93	36.83	45.59	49.91	61.61	58.47	50.19	42.52	37.83	32.96	.....	.....
	3	26.46	29.69	32.07	39.76	51.05	54.68	55.75	57.36	44.19	39.15	34.92	31.98	.....	.....
	Month.	25.89	28.48	31.32	37.44	46.67	51.68	59.81	58.93	50.31	42.26	36.74	32.80	41.86	56.84
1914	1	32.04	.....	.....	36.00	38.72	53.08	56.35	56.96	58.21	52.79	40.11	32.62	.....	.....
	2	31.76	.....	.....	35.02	42.81	55.54	57.83	58.94	56.78	46.77	36.70	.....	.....	.....
	3	.....	.....	32.69	38.74	48.89	61.10	57.42	55.26	55.27	41.95	35.24	.....	.....	.....
	Month.	.....	.....	.....	36.58	43.65	56.57	57.21	56.99	56.75	47.00	37.35	.....	.....	57.07
1915	1	.....	.....	27.53	32.83	37.72	44.35	54.93	53.23	55.65	43.81	44.33	33.05	.....	.....
	2	.....	.....	29.45	37.27	45.20	52.22	60.81	52.10	53.66	40.34	34.97	31.08	.....	.....
	3	.....	.....	31.51	39.39	43.43	53.52	54.70	52.19	51.33	43.15	36.38	30.33	.....	.....
	Month.	.....	.....	29.50	36.50	42.16	50.03	56.75	52.50	53.55	42.45	38.56	31.38	.....	53.37
1916	1	30.60	28.71	34.00	34.65	41.01	53.03	62.19	56.52	56.05	50.91	39.63	32.61	.....	.....
	2	27.31	32.09	39.91	36.78	43.13	54.09	56.67	56.04	47.63	42.71	31.40	25.37	.....	.....
	3	28.43	32.87	39.74	39.44	46.64	57.70	60.24	52.57	50.48	38.72	31.05	20.68	.....	.....
	Month.	28.77	30.48	37.94	36.96	43.69	54.94	59.72	54.94	51.39	43.94	34.03	26.04	41.90	56.51
1917	1	27.55	27.05	27.53	33.30	35.27	42.25	58.03	59.57	53.71	49.39	39.17	31.64	.....	.....
	2	24.92	28.37	27.18	34.96	39.42	53.12	59.79	52.93	50.79	46.71	35.80	30.96	.....	.....
	3	24.96	30.47	32.39	38.20	38.84	58.73	62.10	51.57	47.87	39.91	34.99	33.83	.....	.....
	Month.	25.78	28.50	29.14	35.49	37.88	51.37	60.04	54.59	50.79	45.16	36.65	32.20	40.63	55.18
1918	1	31.96	27.33	35.29	36.72	44.06	50.70	59.07	59.18	54.07	.....	.....	.....	.....	.....
	2	24.29	28.50	37.33	36.61	46.50	58.24	57.50	57.09	50.44	.....	.....	.....	.....	.....
	3	24.45	34.30	37.95	37.13	50.35	57.58	57.62	58.75	.....	.....	.....	.....	.....	.....
	Month.	26.82	29.58	36.89	36.82	47.08	55.51	58.06	58.35	.....	.....	.....	.....	.....	56.98
Average to July 10, 1918	1	28.20	28.26	30.99	35.76	40.74	50.64	58.23	57.47	55.06	48.66	39.11	32.39	.....	.....
	2	27.57	29.85	33.26	36.63	43.81	53.73	58.73	56.41	53.19	44.74	35.79	30.08	.....	.....
	3	27.99	30.74	34.85	39.14	47.44	56.90	57.87	54.53	50.09	40.42	34.36	28.15	.....	.....
	Month.	27.92	29.54	33.09	37.18	44.11	53.76	58.26	56.06	53.11	44.47	36.42	30.14	42.01	56.06

[1] January assumed to be normal. [2] Began using wooden tube.

average variation for eight years of only 1.34°. From this time on, the variation is somewhat greater, owing to the uncertainty of the snow cover; but the variation decreases somewhat at the end of the winter.

(5) The eight growing seasons for which complete records at 1 foot are available show a slightly greater variation—1.24°—than the six whole years; but the six growing seasons corresponding to the six whole years show practically the same variation, 1.04°.

(6) The annual oscillation of soil temperatures, as determined from the decade means, is for 1 foot 31.4°, and for 4 feet 22.7°; but the corresponding oscillation of air temperatures is 35.9°, this greater oscillation of the air being due to winter depression when the soil is more or less blanketed with snow. The lowest average soil temperatures occur in the second decade of January, while the lowest mean

TABLE 26.—*Mean soil temperatures at the control station (F–1)—2 and 4 feet.*

Year.	Decade.	January.	February.	March.	April.	May.	June	July.	August.	September.	October.	November.	December.	Mean annual.	Growing season.
1910	1	.....	.....	31.98	40.51	44.47	55.25	59.27	59.07	59.22	55.53	45.92	38.54	.....	.....
	2	.....	30.64	34.82	40.20	46.18	57.59	60.24	58.28	59.62	54.03	43.37	37.04	.....	.....
	3	.....	30.93	40.83	43.64	47.53	60.72	62.01	58.44	56.55	47.33	41.44	33.94	.....	.....
	Month.	(1)	30.75	36.04	41.25	46.11	57.85	60.55	58.59	58.46	52.14	43.58	36.42	46.10	59.01
1911	1	31.21	36.68	33.70	40.27	44.74	55.47	58.29	60.67	56.85	55.37	40.49	34.37	.....	.....
	2	32.96	35.77	35.90	39.58	50.59	58.03	58.43	61.51	58.60	52.45	39.99	33.11	.....	.....
	3	34.80	33.83	36.85	42.83	50.85	58.41	57.33	57.07	58.04	45.22	37.81	32.19	.....	.....
	Month.	33.05	35.54	35.53	40.89	48.80	57.30	57.99	59.66	57.83	50.83	39.43	33.19	45.84	58.21
1912	1	29.62	31.27	30.86	35.82	41.66	51.94	56.52	58.31	59.92	48.83	39.93	34.52	.....	.....
	2	30.23	31.54	31.80	38.10	39.14	48.61	58.22	58.09	54.18	47.15	38.91	33.05	.....	.....
	3	31.35	30.57	32.06	36.49	50.22	51.10	58.05	59.76	49.31	45.07	36.73	30.10	.....	.....
	Month.	30.43	31.14	31.59	36.80	43.56	50.55	57.61	58.75	54.47	46.95	38.52	32.48	42.74	56.05
1913	1	29.43	29.44	30.71	36.19	44.07	52.09	61.51	61.94	58.89	48.49	40.28	35.82	.....	.....
	2	28.65	30.33	31.92	37.40	46.17	51.12	61.94	59.68	54.52	46.21	40.45	35.09	.....	.....
	3	29.19	30.96	32.02	40.33	51.06	55.01	58.07	59.10	48.71	42.52	38.11	34.13	.....	.....
	Month.	29.13	30.19	31.56	37.97	47.22	52.74	60.43	60.20	54.04	45.64	39.61	34.98	43.64	57.94
1914	1	33.80	.....	.....	36.75	39.12	53.33	57.84	.....	.....	.....	.....	.....	.....	.....
	2	33.50	.....	.....	35.97	43.66	56.39	.....	.....	.....	.....	.....	.....	.....	.....
	3	.....	.....	33.49	39.41	49.19	61.63	.....	.....	.....	.....	.....	.....	.....	.....
	Month.	.....	.....	.....	37.37	44.16	57.12	.....	.....	.....	.....	.....	.....	.....	.....
Average[2]	1	31.02	32.46	31.81	37.91	42.81	53.62	58.69	60.00	58.72	52.06	41.66	35.81	.....	.....
	2	31.34	32.07	33.61	38.25	45.15	54.35	59.71	59.39	56.73	49.96	40.66	34.57	.....	.....
	3	31.78	31.57	35.04	40.54	49.77	57.37	58.86	58.59	53.15	45.04	38.52	32.59	.....	.....
	Month.	31.39	32.02	33.54	38.90	46.03	55.11	59.06	59.10	56.20	48.89	40.29	34.27	44.57	57.93
1914	1	.....	.....	.....	.....	.....	.....	.....	56.66	56.51	56.04	47.33	40.78	.....	.....
	2	.....	.....	.....	.....	.....	.....	[3]55.98	57.11	56.95	53.63	45.37	.....	.....	.....
	3	.....	.....	.....	.....	.....	.....	55.93	57.01	56.85	50.76	42.60	.....	.....	.....
	Month.	.....	.....	.....	.....	.....	.....	56.56	56.92	56.77	53.40	45.10	38.50	.....	.....
1915	1	.....	.....	32.36	32.97	39.41	43.84	50.83	53.64	54.04	50.65	46.85	40.01	.....	.....
	2	.....	.....	32.22	35.53	41.14	46.53	53.95	53.25	54.16	48.09	44.07	38.70	.....	.....
	3	.....	.....	32.43	37.68	42.88	49.39	54.20	52.91	53.78	46.55	41.90	36.84	.....	.....
	Month.	.....	.....	32.34	35.39	41.20	46.75	53.03	53.26	53.99	48.37	44.27	38.52	.....	51.31
1916	1	35.70	33.27	35.66	39.41	40.77	48.39	55.40	57.08	55.98	53.99	47.28	39.81	.....	.....
	2	35.01	33.22	38.15	38.83	43.94	50.72	56.42	57.18	55.11	51.95	44.22	38.08	.....	.....
	3	34.02	34.55	40.63	40.27	44.35	52.93	57.05	56.35	53.80	48.35	41.42	35.38	.....	.....
	Month.	34.88	33.65	38.19	39.50	43.06	50.85	56.32	56.85	54.96	51.33	44.31	37.67	45.13	54.80
1917	1	34.00	32.89	33.16	33.78	38.13	40.96	52.95	56.70	54.00	52.43	46.50	41.46	.....	.....
	2	33.96	33.00	32.92	35.58	37.84	46.20	53.86	55.41	54.16	51.94	45.36	38.84	.....	.....
	3	33.09	33.04	32.82	37.92	40.37	50.09	55.66	54.13	52.97	49.23	42.96	38.96	.....	.....
	Month.	33.66	32.97	32.96	35.76	38.84	45.75	54.21	55.37	53.71	51.14	44.94	39.73	43.25	52.00
1918	1	39.24	33.75	36.04	38.39	40.80	48.72	55.92	56.90	56.09	.....	.....	.....	.....	.....
	2	36.59	34.23	37.53	38.14	43.98	51.76	55.67	56.35	53.59	.....	.....	.....	.....	.....
	3	34.65	35.05	38.39	37.53	47.45	54.35	55.87	56.92	.....	.....	.....	.....	.....	.....
	Month.	36.75	34.29	37.35	38.02	44.15	51.61	55.82	56.73	.....	.....	.....	.....	.....	54.86
Average to July 10, 1918	1	36.31	33.80	34.30	36.14	39.78	45.60	53.78	56.02	55.13	53.28	46.99	40.52	.....	.....
	2	35.19	33.48	35.20	37.02	41.72	48.80	55.05	55.74	55.10	51.40	44.76	38.53	.....	.....
	3	33.92	33.96	35.81	38.35	43.76	51.82	55.71	55.10	54.35	48.97	42.22	37.06	.....	.....
	Month.	35.10	33.55	35.13	37.17	41.82	48.74	54.87	55.60	54.86	51.14	44.66	38.65	44.27	53.28

[1] January assumed to be normal.
[2] Average (2 feet) February, 1910, to July 10, 1914.
[3] Record at 4 feet begins.

air temperatures are not to be expected until four decades later, an unusually late time, as has been explained in the discussion of air temperatures. The highest average soil temperatures occur one decade earlier than the highest mean air temperatures, the former being slightly in excess of the latter, a fact which is made the more certain by considering the low value of the soil temperatures recorded at 8 a. m. The extremes at 4 feet occur two decades later than those at 1 foot.

(7) At this station and at practically all others the soil temperature rises in the first or second decade of September. This results from the usual cessation of rains and cloudiness near the end of August. Six years out of eight show this characteristic.

Soil temperatures evidently vary by years in about the same manner and degree as air temperatures, and corresponding periods of different years may exhibit quite different characteristics. Notwithstanding these facts, it has been decided to accept each soil-temperature record from the other stations at its face value, without attempting, as was done with air temperatures, to compare it with the control station for the same period. The reasons for this decision may be stated as follows:

(1) Most of the records here presented cover periods of three years or more, with the consequent opportunity for partial compensation of variations.

(2) The failure to determine mean 1-foot temperatures more directly makes great precision in this phase of the study impossible.

Absolute soil temperatures of the types.—The records for each of 20 stations, by months, are accordingly presented in Tables 27 and 28, the period of observation for each station being shown. Figures 5 and 6 show some typical soil-temperature relations.

Table 27 discloses that considerable differences in soil temperatures may exist between sites which are similar as to forest cover. These are equal to or greater than the air-temperature differences between the same sites. Since it is apparent that soil temperatures at a depth of a foot or more can have little direct bearing on growth, as temperature factors, there will at first be an inclination to say that soil temperatures are not so good criteria of the possibilities of the site as air temperatures are, provided the latter are taken close enough to the ground to represent those conditions most directly affecting germination and seedling growth. As has been said, however, the tables show that mean soil temperatures, even for whole years, do not bear a constant relation to the air temperatures of the respective sites. When it is also considered that the latter have not always been measured where they would best show the conditions surrounding seedlings, and as the soil-temperature measurements do bear a certain fairly definite relation to surface conditions, it is seen that soil temperatures may have a special significance, at least in indicating the degree of insolation of the site, and the maximum temperatures which the seedlings will encounter. It is now believed that the maximum temperatures near the surface of the soil are of the greatest importance in the distribution of the species, and it is for this reason that the 1-foot temperatures during the growing season will be considered in the greatest detail.

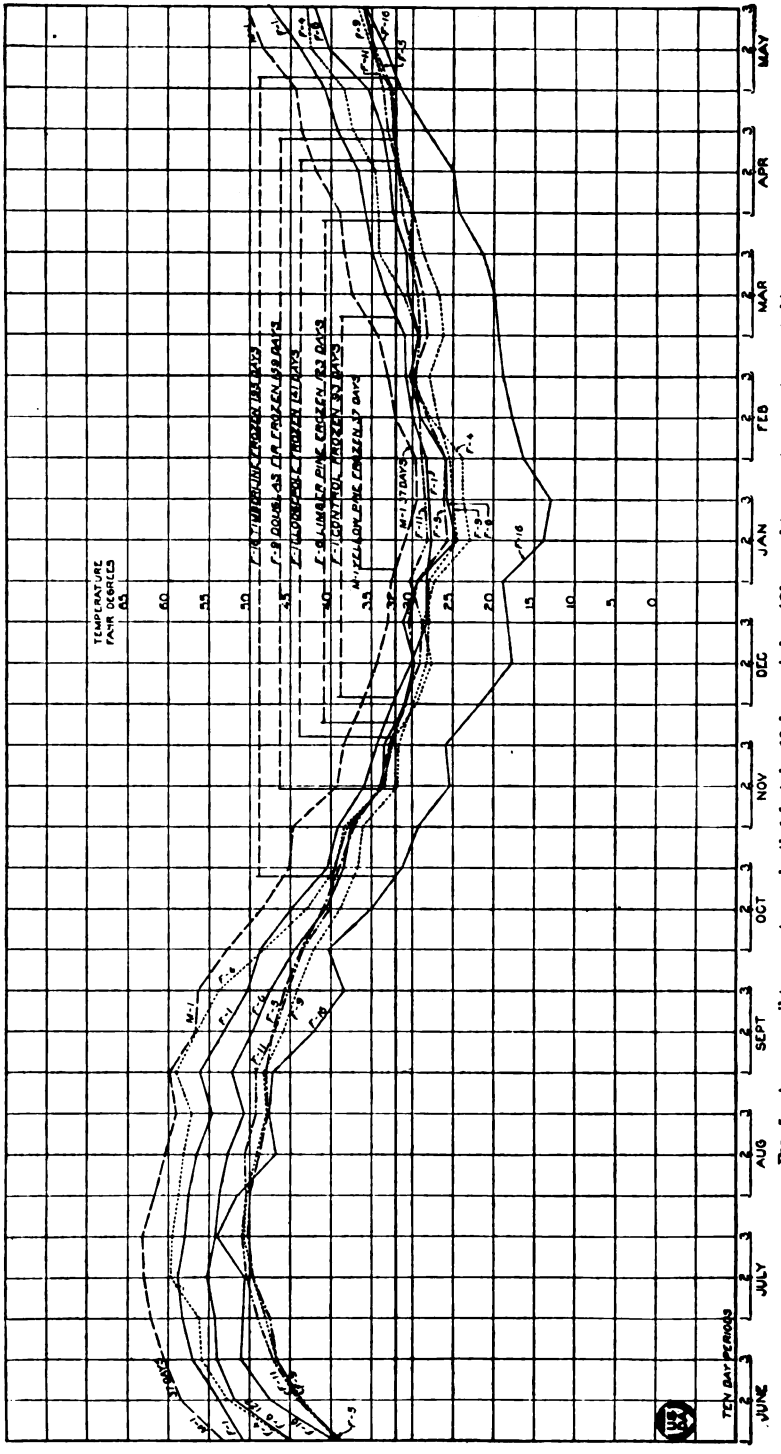

FIG. 5.—Average soil temperatures, depth 1 foot, by 10-day periods. (Observed temperatures, not corrected.)

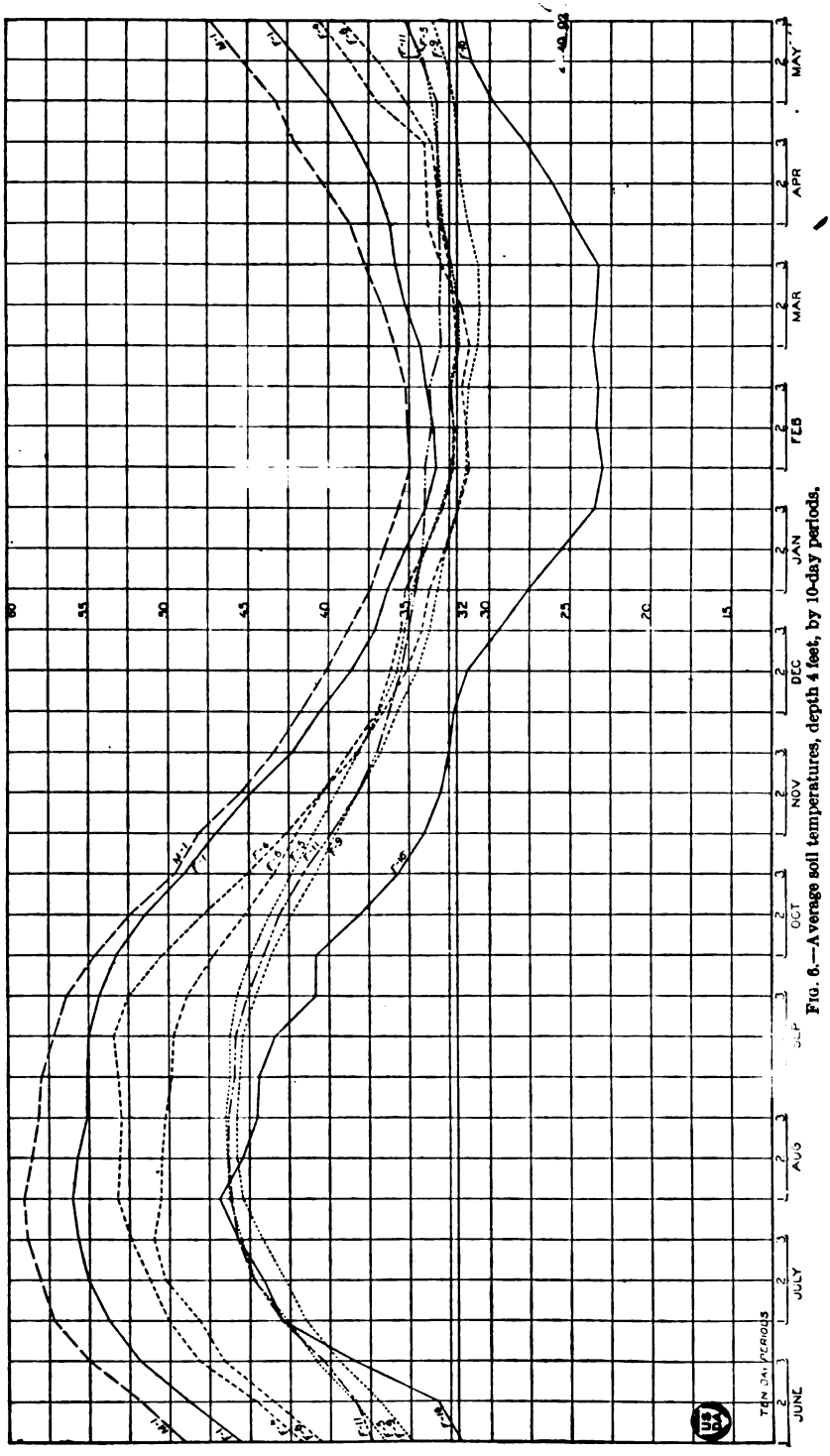

FIG. 6.—Average soil temperatures, depth 4 feet, by 10-day periods.

TABLE 27.—*Summary of mean soil temperatures for all stations—depth, 1 foot.*

[Parenthetical figures indicate number of decade in which highest or lowest temperature is reached.]

Station No.	Locality.	Forest type.	Period of observations.	Record, by months, in degrees Fahrenheit.												Mean annual.[1]	Mean growing season.[1]	Corrected according to Table 24.	
				Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.			Mean annual.[1]	Growing season.[1]
F-1	Pikes Peak	Control	Jan., 1910, to July, 1918.	(2) 27.9	29.5	33.1	37.2	44.1	53.8	(2) 58.3	56.1	53.1	44.5	36.4	30.1	42.01	56.06	44.93	58.98
H-2	Nebraska	Sandhills	Nov., 1918, to June, 1921.	(3) 30.3	30.1	35.5	43.8	56.7	67.5	(3) 75.0	72.5	65.9	50.5	36.7	32.3	49.73	71.32	50.78	72.37
M-1	Pikes Peak	Western yellow pine.	Jan., 1915, to July, 1918.	(3) 30.9	31.4	36.7	41.4	47.8	57.2	(3) 62.7	60.3	57.6	48.6	40.7	34.4	45.82	60.06	46.46	60.70
F-2	do	do	Feb., 1910, to Feb., 1912; Mar., 1913, to Dec., 1913; May to Dec., 1914; Mar., 1915, to Feb., 1916; May, 1917, to July, 1918.	(1) 31.0	32.9	36.6	39.8	45.1	55.5	(2) 58.4	57.1	57.2	48.3	40.8	34.2	44.75	57.15	45.76	58.16
F-12	do	do	June, 1915, to Feb., 1916; May, 1917, to July, 1918.	27.8	(1) 28.4	30.2	35.1	41.6	51.4	(2) 58.3	54.8	52.0	42.4	36.0	30.9	40.74	54.80	41.52	55.58
F-4	do	Pine-fir	July, 1914, to Feb., 1916; May, 1917, to July, 1918.	(2) 24.6	27.0	31.6	35.4	41.4	51.0	(2) 58.4	57.9	56.4	43.4	34.8	28.5	40.86	56.09	41.20	56.43
F-6	do	Limber pine	July, 1914, to Feb., 1916; May, 1917, to July, 1918.	(2) 26.5	28.1	30.2	33.0	39.3	50.0	(2) 54.4	52.2	49.7	41.0	34.9	30.5	39.15	52.23	40.32	53.40
F-7-8	do	Douglas fir, open.	July, 1914, to July, 1918.	(2) 20.9	22.5	27.3	32.5	38.1	49.6	(3) 56.2	53.7	48.6	38.9	29.9	23.9	36.84	53.04	37.94	54.14
F-14	do	Douglas fir, half cut	Apr., 1916, to July, 1918.	(2) 23.8	24.9	28.1	31.6	35.1	45.4	(3) 52.1	51.1	46.3	38.5	30.7	26.4	36.17	49.51	37.28	50.62

F-15	do	do	do	(2) 24.1	25.3	28.2	31.5	35.5	47.3	(3) 53.5	51.0	45.5	38.3	31.2	27.2	36.56	50.42	37.53	51.39
W-A2	Rio Grande	Douglas fir, south.	Jan., 1913, to July, 1918.	28.9	(1) 28.7	30.6	33.9	39.8	50.0	(2) 54.6	52.8	48.9	43.5	38.8	32.6	40.26	52.38	43.42	55.54
W-A1	do	Douglas fir, north.	Apr., 1912, to July, 1918.	19.3	(2) 19.3	21.4	26.4	31.9	37.5	45.7	(1) 47.2	40.7	33.3	28.1	21.0	30.97	43.56	31.35	43.94
F-9	Pikes Peak	Douglas fir-spruce, uncut.	July, 1914, to July, 1918.	(2) 25.7	26.6	27.2	31.2	34.9	43.0	(3) 49.3	49.0	46.0	39.0	33.1	28.6	36.14	47.23	37.08	48.17
F-11	Southern Wyoming.	Lodgepole	Aug., 1914, to July, 1918.	(2) 23.9	29.1	29.6	31.6	34.7	43.3	(3) 50.0	50.0	47.1	40.6	34.3	29.4	37.37	47.88	38.56	49.07
F-13	Pikes Peak	Limber pine	June, 1915, to Sept., 1916.	(3) 23.1	26.3	33.5	33.8	41.0	51.0	(1) 57.5	50.2	48.4	37.4	32.0	25.8	38.34	52.81	.....	.....
F-5	do	Engelmann spruce, canyon.	Same as F-2	26.4	(1) 26.4	29.9	32.0	36.3	47.6	(2) 52.1	50.4	46.9	38.4	32.6	28.7	37.31	49.92	38.02	50.63
F-5	do	do	June to Dec., 1914; Mar., 1915, to Feb., 1916; May, 1917, to July, 1918.	27.0	(1) 27.8	28.9	31.7	34.4	42.9	(3) 49.0	48.7	46.9	41.0	34.5	30.2	36.93	46.97	38.33	48.37
W-F	Rio Grande	Engelmann spruce, north slope.	Nov., 1913, to Dec., 1917.	(1) 26.9	27.5	27.6	29.1	31.0	33.6	42.0	(1) 44.5	39.8	32.9	29.3	26.7	32.56	40.00	32.90	40.34
W-D	do	Spruce burn, flat.	Dec., 1913, to Nov., 1918.	(2) 28.0	28.6	29.5	31.1	33.1	44.8	(3) 53.3	52.7	47.6	40.6	32.9	28.8	37.58	50.01	37.63	50.06
F-16	Pikes Peak	Timber line	Oct., 1916, to Feb., 1918.	(3) 15.2	17.6	20.2	25.9	33.5	45.9	(3) 51.8	48.5	42.4	35.3	26.8	19.2	31.86	48.55	33.24	49.93

[1] Annual and growing-season means computed from decade and monthly values carried to hundredths. Growing season is arithmetic mean of 10 decades, except Stations W-D and W-F.

TABLE 28.—*Summary of mean soil temperatures for all stations—depth, 4 feet.*[1]

Station No.	Locality.	Forest type.	Record, by months, in degrees Fahrenheit.											Mean annual.[2]	Mean growing season.[2]
			January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
F-1	Pikes Peak	Control	35.1	33.6	35.1	37.2	41.8	48.7	54.9	55.6	54.9	51.1	44.7	38.6	44.27	53.28
H-2	Nebraska	Sandhills	36.8	35.5	37.2	43.5	52.2	61.1	67.4	68.3	65.5	57.6	45.2	39.1	50.78	65.67
M-1	Pikes Peak	Western yellow pine	36.5	35.1	36.8	40.3	45.3	51.9	58.1	58.6	57.2	52.1	45.6	40.1	46.46	56.38
F-2	do	do	37.5	36.5	37.0	38.8	42.4	48.3	53.8	55.0	55.6	52.2	47.1	41.6	45.49	52.66
F-12	do	do	34.3	32.6	32.9	35.4	39.4	45.2	50.8	51.7	51.0	46.4	41.6	37.0	41.52	49.41
F-4	do	Pine-fir	32.8	31.4	32.0	33.9	38.8	44.9	51.2	53.1	53.0	47.7	40.4	35.2	41.20	50.07
F-6	do	Limber pine	34.0	32.3	32.2	33.3	37.1	43.6	49.8	50.4	49.5	45.2	40.4	36.2	40.32	48.12
F-7-8	do	Douglas fir, open	30.3	29.0	30.1	31.8	33.2	41.1	48.2	50.2	48.6	43.3	37.0	33.0	37.94	46.78
F-14	do	Douglas fir, half cut	30.7	29.6	30.2	31.7	32.3	38.8	46.4	48.8	46.9	42.4	36.4	33.1	37.28	45.00
F-15	do	do	31.5	30.2	30.6	31.9	32.4	39.7	46.9	48.6	46.2	42.0	36.7	33.6	37.53	45.29
W-A2	Rio Grande	Douglas fir, south	36.8	35.2	35.3	37.1	40.9	46.5	51.8	52.8	51.9	48.7	45.2	40.2	43.54	50.57
W-A1	do	Douglas fir, north	26.4	25.2	25.2	26.4	31.3	32.6	36.6	40.6	38.7	33.3	30.8	29.4	31.39	36.98
F-9	Pikes Peak	Douglas fir-spruce, uncut	32.6	31.4	30.7	31.7	32.8	37.1	42.9	45.7	45.2	42.2	38.1	34.6	37.08	42.26
F-11	Southern Wyoming	Lodgepole pine	34.3	33.8	33.0	33.2	34.3	38.8	44.5	46.3	45.6	42.9	38.3	35.5	38.35	43.43
F-13	Pikes Peak	Limber pine	28.6	28.6	32.4	33.6	39.9	49.3	54.6	51.2	49.2	40.2	35.6	30.2	39.45	51.65
F-3	do	Engelmann spruce, canyon.	33.6	32.0	31.6	32.6	34.2	40.2	45.5	46.8	45.8	42.0	38.0	34.8	38.06	44.36
F-5	do	do	33.9	32.3	32.0	33.0	34.8	38.7	44.3	46.4	46.0	43.6	39.5	35.9	38.33	43.42
W-F	Rio Grande	Engelmann spruce, north slope.	31.8	31.4	31.3	31.4	31.6	32.0	32.3	35.7	37.4	35.0	32.8	32.2	32.90	33.73
W-D	do	Spruce burn, flat	33.3	32.6	32.3	32.3	32.3	35.8	43.8	47.3	46.2	43.2	37.9	34.6	37.63	42.69
F-16	Pikes Peak	Timberline	25.4	23.2	23.4	26.2	30.9	34.6	44.3	45.6	42.8	38.1	33.2	31.0	33.24	41.79

[1] Period of observations same for 4 feet as for 1 foot, except that former do not begin until July, 1914, for local stations; July, 1913, for Wagon Wheel Gap stations; and April, 1916, for F-11.

[2] See footnote to Table 27.

Extremely low air temperatures in winter may be made more severe by melting snow in the vicinity, which, as it melts, tends to absorb most of the sun's heat. On the other hand, the snow blanket tends to hold up the soil temperatures and to prevent deep freezing. Thus, although the lodgepole pine type in Wyoming (Station F–11) has a mean air temperature practically equivalent to that of timber line at Pikes Peak, its mean soil temperature is some 5° higher and its winter soil temperature is 11° higher. Again, the high-altitude spruce station at Wagon Wheel Gap has practically the same mean annual air and soil temperatures as the timber line station on Pikes Peak; but while the latter's January soil temperature drops to 15.2° F. the former reaches a low point of only 26.9° F. The difference is due to lack of snow cover at the timber line station, and, similarly, the lack of forest cover gives this station much higher summer soil temperatures.

In Table 29, both air temperatures and 1-foot soil temperatures have been summarized in such a way as to bring out the contrasts which exist at different seasons, and to show that soil temperatures and air temperatures do not give similar measures of site conditions. The differences between soil and air temperatures are to some extent illustrated in Figures 7 and 8. It must, of course, be borne in mind that the air temperatures given in this table are approximations to the "normals" for the period 1910 to 1918, by comparison with the control station, but that the soil temperatures represent shorter periods, and somewhat different periods for different stations.

TABLE 29.—*Comparative air and soil temperatures.*

[Soil temperatures in degrees Fahrenheit at 1 foot, corrected for year and growing season by amounts indicated in Table 24; for winter, by one-half of these amounts.]

Station No.	Forest type.	Annual temperatures.			Growing-season temperatures.			Winter (Jan.–Mar.) temperatures.		
		Air.	Soil.	Difference.	Air.	Soil.	Difference.	Air.	Soil.	Difference.
H–2	Sandhills	47.47	50.78	+3.31	70.81	72.37	+ 1.56	29.87	32.00	+ 2.13
M–1	Western yellow pine.	43.96	46.46	+2.50	61.56	60.70	− 0.86	29.43	33.32	+ 3.89
F–2	do	42.23	45.76	+3.53	58.65	58.16	− 0.49	29.10	34.02	+ 4.92
F–12	do	39.98	41.52	+1.54	56.65	55.58	− 1.07	25.84	29.19	+ 3.35
F–4	Pine-fir	.....	41.20	.....	54.00	56.43	+ 2.43	.....	27.90	.....
F–7–8	Fir with pine	39.69	37.94	−1.75	56.68	54.14	− 2.54	25.70	24.12	− 1.58
W–A2	do	37.54	43.42	+5.88	55.98	55.54	− 0.44	22.67	30.98	+ 8.31
F–15	Douglas fir	39.58	37.53	−2.05	56.52	51.39	− 5.13	25.50	26.36	+ 0.86
F–14	do	39.23	37.28	−1.95	56.58	50.62	− 5.96	25.03	26.16	+ 1.13
F–9	Fir with spruce	38.77	37.08	−1.69	55.78	48.17	− 7.61	24.77	26.97	+ 2.20
W–A1	do	35.76	31.35	−4.41	54.18	43.94	−10.24	20.87	20.19	− 0.68
F–3	Engelmann spruce	38.91	38.02	−0.89	55.95	50.63	− 5.32	25.40	27.92	+ 2.52
F–5	do	.....	38.33	.....	50.98	48.37	− 2.61	.....	28.60	.....
W–F	do	32.13	32.90	+0.77	49.53	40.34	− 9.19	18.03	27.50	+ 9.47
F–16	Timberline	31.63	33.24	+1.61	48.96	49.93	+ 0.97	17.83	18.36	+ 0.53
F–11	Lodgepole pine	32.49	38.56	+6.07	49.94	49.07	− 0.87	18.30	29.80	+11.50
F–6	Limber pine	41.92	40.32	−1.60	59.02	53.40	− 5.62	27.50	28.86	+ 1.36
F–13	do	37.01	38.34	+1.33	54.39	52.81	− 1.58	23.67	27.63	+ 3.96

In Table 29, certain relations stand out in bold relief, as, for example, the ability of the soil of well-insolated sites to equal or even exceed the air temperatures during the growing season, although the north slopes and those covered by the denser stands fail to do this by 2.5° to 10.2°. It is significant that all of the warmer sites

encourage pines in some degree. These and other relations will be further analyzed in the following discussions of the types.

(1) The yellow pine sites—M–1 at 7,200 feet elevation and F–2 1,700 feet higher—show nearly the same soil temperatures at all seasons, although the constant difference between the two is even greater than the difference in air temperatures near the ground. These two stations are almost in a class by themselves. However, it is to be noted that F–1, the control station, practically measures up to yellow pine standards, its 4-foot mean being as high as that at Station F–2. Stations F–12 and F–4, both representing sites in which the yellow pine tends to give way to Douglas fir and limber pine, show soil temperatures a little below the yellow pine standard.

That the growing-season temperatures indicated above as being favorable to yellow pine will not fall far short of those occurring in

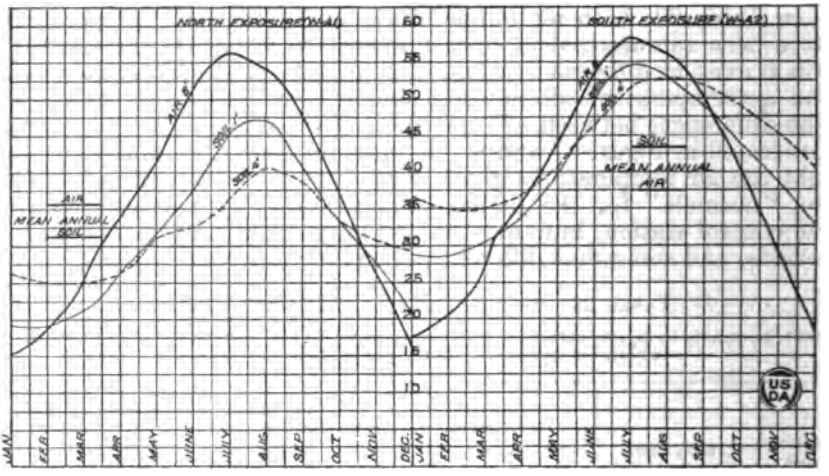

FIG. 7.—Relation of soil and air temperatures on opposing slopes.

any of the yellow-pine sites of this region is indicated by numerous measurements made in the Black Hills region in 1914, when, during June, July, and August, soil temperatures at 1 foot ranging from 56° to 65° were continually encountered.[7] Although measurements are lacking, there is little doubt that winter soil temperatures are kept up fully as high as in the Pikes Peak region, notwithstanding much lower air temperatures, through the agency of a heavy snow blanket in the Black Hills. Larsen (*13*) shows an August mean of 65° at 1 foot, for the Idaho western yellow pine site, as compared with about 63° at Monument in July. Pearson (*19*) gives May to October values ranging from 53.1° to 66.2° for a number of pine sites in the Southwest.

In the typical western yellow-pine sites the soil temperature at 4 feet does not, for any 10-day period, go so low as 32°. At Station

[7] Five measurements in three Quality I pine sites, between June 24 and July 8, showed an average temperature of 57.7°, 1° lower than Station F–1 for the same period. Thirty observations in 14 Quality II sites, June 22 to July 31, gave a mean temperature of 59.7°, 1.5° higher than the control station. Twenty-two observations in 10 Quality III sites gave a mean of 58.9°, or 1.5° above the control station for the period July 11 to August 3. From this it appears that the moister and better sites are appreciably cooler than yellow-pine sites in the Pikes Peak region. This difference may be due wholly to denser stands in the Black Hills. On the whole, the two localities are more similar than might be expected. The average of all Black Hills observations, June 22 to August 3, was 59.2°, and for the control station 57.9°.

F–4 the soil normally is frozen at the 4-foot depth for 5 or 6 decades. The Nebraska sandhill soil has not, so far, closely approached freezing at the 4-foot depth.

One of the reasons, therefore, for the crowding out of yellow pine by Douglas fir and for the producing of a "succession" in the truest sense, may be the shade of the mother canopy, which induces a prolonged winter drought for the small trees. In the one situation where this is fairly represented (F–4) the condition of the parent trees, as well as the composition of the reproduction seems to show the severity of the strain so produced. However, it should be observed that a heavy canopy at the same time so reduces the exposure of each tree or seedling that the immediate and radical effects of winter drying, commonly described as "winter-killing," are not observed in the fairly dense forest.

(2) It may be well to examine next the limber pine sites, represented by F–6 and F–13. Notwithstanding the fact that the second

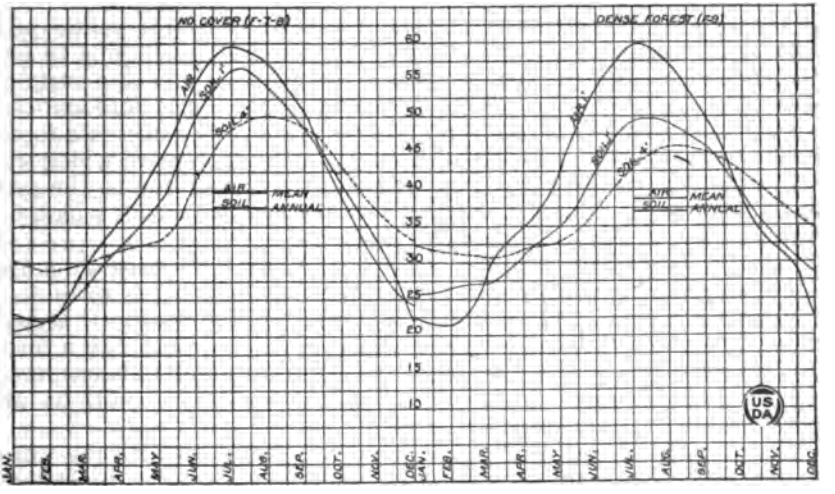

FIG. 8.—Relation of soil and air temperatures with and without forest cover north slopes.

station represents almost the upper limits of the species, its mean temperatures are almost equivalent to those of the lower station, and its growing-season temperatures slightly higher, because of a bare and well-insolated soil. The relatively high values at either station give emphasis to the argument that limber pine seedlings thrive under intense radiation, and that the necessary heat for growth, at elevations where the air temperatures are generally low, is secured on burns and rocky ridges through purely local absorption of heat by the ground. It is probable that the maxima attained in the soil and immediately above it will fall little short of those for yellow-pine sites. Also the winter soil temperatures of these sites are considerably higher than the air temperatures, especially at the higher elevation. In mean soil temperatures the sites correspond closely to the quasi-yellow-pine sites, but in neither of the limber-pine sites is freezing to a depth of 4 feet to be expected. This conclusion for Station F–13 is reached after a consideration of the relative winter temperatures at 1 and 2 feet.

The writer believes, however, that there are situations occupied by limber pine in which the winter soil temperatures go considerably below those characteristic of yellow-pine sites, permitting freezing of the soil for long periods. The ability of limber pine to exist under such circumstances, and with extreme wind exposure, points to a marked difference in adaptation, between this species and yellow pine, which may be quite independent of their apparently similar heat requirements.[8] There has come to the writer's notice what may be called an adaptation of outward form, by which during the winter the needles of limber pine become very closely appressed. This gives the limbs a club-like appearance quite different from the "feathery" one of summer.

It is therefore quite evident that while limber pine has heat requirements similar to those of western yellow pine, which are satisfied by the conditions resulting from the insolation of bare, exposed soils, it has also a faculty for resisting winter-drying, which permits the species to range almost from the lower limits of yellow pine to points practically equivalent to timber line, not reached by the yellow pine. This heat requirement makes it possible for the limber pine to be a forerunner of Douglas fir or spruce on gravel slides too strongly insolated to admit the other species, and on burns and cut-over areas, but excludes it from a prominent place in the ultimate forest.

That limber pine is nowhere more abundant nor more widely distributed than in the Pikes Peak region is, perhaps, due to the presence of a young, denuded soil and to other soil properties which will be discussed in the section on soil moisture.

(3) The conditions brought out by the Douglas fir sites are amply illustrative of the soil-temperature variations which are possible in different localities. These conditions give the impression that both winter and summer soil temperatures may have a bearing on forest composition, but that at times the conditions are not fully expressed by the soil temperatures alone—that atmospheric conditions also must be taken into account.

The data for Douglas fir, considered in connection with the quasi-yellow-pine sites, on the one hand, and the conditions in Douglas fir sites which seem to encourage spruce reproduction, on the other, may be summarized as follows:

(*a*) Sites on which Douglas fir reproduction will about maintain the predominant position of this species (F–14, 15) are characterized by an annual mean soil temperature of about 37° F., a growing-season mean of 51°, and a winter mean of 26°, with the soil at 1 foot frozen for about 140 days.

(*b*) Greater insolation and radiation, secured on a similar site (F–7–8), by complete removal of the cover, create summer soil temperatures about 3° higher, and winter temperatures 2° lower, the freezing period being somewhat earlier. The summer conditions undoubtedly encourage more germination of western yellow and limber pines, but the winter conditions will probably keep the pines to a very subordinate position in the ultimate composition of the stands.

(*c*) Sites in the Pikes Peak region (F–4 and 12) better insolated than the last, but having their summer extremes modified by fairly heavy cover, favor western yellow and limber pines with the fir, but appear to be progressing steadily toward pure fir stands.

(*d*) A site (W–A2) having much more insolation than the last because of a south exposure and a scant cover, scarcely warmer than the "normal Douglas fir" sites in summer, but 4° warmer in winter, and not freezing to a depth of

[8] An exception was noted early in July, 1917, when with air and soil unusually dry, limber pines in an open stand on a southeast slope showed foliage injury exactly corresponding to winter-killing, while yellow pines on the same site escaped without apparent injury.

4 feet, is very discouraging to any kind of reproduction, but permits some bristlecone pine as well as fir. The entrance of bristlecone rather than yellow pine under these conditions may, perhaps, be taken as evidence of dissimilar soil preferences of the two pines.

(*e*) Additional density of cover on a north slope (F–9) reduces the extremes of soil temperature 1° or 2° without appreciably affecting the period of soil freezing. This change of temperature extremes, which would be much more apparent if absolute maxima and minima nearer the surface could be considered, is conducive to better germination of both spruce and fir, but results in an undergrowth controlled by spruce.

(*f*) A site not unlike the last in its air-temperature conditions (W–A1) may show much lower soil temperatures at all seasons (4° to 6°) without appreciably changing the character of the reproduction. The two sites are most similar during the growing season, both in absolute soil temperature and in having soil temperatures much (8° to 10°) below the air temperatures. They vary widely in the severity of their soil freezing; but, when atmospheric conditions in this period are considered, they are found to be not so unlike. (See Table 30.)

(4) The soil temperatures of the four spruce sites here considered cover a wide range, the mean annual temperatures for the 4-foot depth varying from about 38° on the two sites at 9,000 feet elevation to 33° at or near timberline. The timberline station at Fremont and the north-slope station at nearly the same elevation at Wagon Wheel Gap show essentially the same mean temperatures; but temperatures for the timberline station go to much greater extremes, owing to the lack of forest cover at the observation point, and the lack of a snow blanket in winter.

When the canyon spruce sites (F–3 and F–5) are compared with the north-slope fir site of the same locality in which spruce reproduction is encouraged (F–9), it is found that the former have equal or higher soil temperatures during the growing season and warmer and less deeply frozen soils during the winter. Of all sites, these canyon bottoms would be the last on which fir would be found. The spruce may also control the lower and, perhaps, the coldest portion of the fir slope. It is then evidently not the soil temperature conditions which exclude fir and permit excellent reproduction and development of the spruce. The character of the soil at the foot of the slope and in the canyon bottom is suggestive, as something in common for these two sites, and after soil-moisture conditions are considered, it must be admitted that soil quality and moisture and not soil temperature seem to be the controlling factors in this situation.

The timberline station on Pikes Peak (F–16), where the soil receives full insolation, attains to summer soil temperatures almost equal to those at the lower (canyon) limit of spruce. In view of this fact, as well as the great intensity of sunlight at the high elevation, it is evident that the heat conditions for a reasonable growth each season are fully satisfied. By comparison with a similar elevation at Wagon Wheel Gap, however, the effect of the canopy in modifying temperature extremes is plainly seen and it becomes evident that near timberline the forest may have a tendency to choke itself by creating soil conditions not conducive to vigorous reproduction. In other words, at a certain point the temperature will not permit a permanently dense stand. The result is that in thinner stands each individual tree during the long winter is subjected to an exposure which can not be tolerated beyond a certain point. The temperature conditions at different seasons are thus all interrelated in limiting the

upward extension of the forest and in permitting the initiation of single specimens only in sheltered nooks, where there is no room for a self-protecting group or stand and where there is indeed insufficient protection for the individual when it reaches above the level of rocks or of the usual snow blanket.

A mean annual air and soil temperature of 32° may be approximately limiting to growth on fully exposed sites, although there is little question that some excellent spruce forests exist and produce very satisfactory wood increments where this temperature is closely approached. Low temperatures may directly preclude normal development of stands during the growing season, and they may react, through the long period of soil freezing, to create a very great winter exposure; but it becomes evident that it is the winter exposure which directly creates a "timberline."

(5) The single lodgepole pine station shows mean soil temperatures similar to those of the spruce type, but its winter temperatures are more nearly those of the western yellow pine type.

(6) To summarize: Soil temperatures are more responsive to the local effects of insolation than air temperatures are, and even the soil temperatures at a depth of 1 foot are probably more representative of those conditions at the surface of the ground that affect germination and the young seedling than are air temperatures as they are usually and conveniently measured. Consequently, soil temperatures bring out more closely than air temperatures the growing-season contrasts between north and south slopes, between forested and open sites, and between the heat of bare or rocky soils and older or better-protected soils. Every soil-temperature difference in a single locality such as the Pikes Peak region is accompanied by a change in the character of the forest reproduction, although in some cases it is doubtful if the soil temperature is the controlling condition. Yellow pine, limber pine, and bristlecone pine all appear to enjoy warm soils and to reproduce on sites where very high temperatures are to be expected, at least for short periods. Douglas fir, on the other hand, reproduces well only with sufficient shade to greatly modify these high temperatures. This is true in the Pikes Peak region even on northerly slopes where the sun's rays strike obliquely. The distinction between Douglas fir and Englemann spruce does not seem to be so much a matter of temperatures which might injure young seedlings, as of soil or light conditions which in the dense forest gradually starve the fir. This distinction may be more logically discussed after considering the soil moisture data.

Evaporation during the period of soil freezing.—In accordance with what has been shown in Table 29 as to the variation in the extent of soil freezing in the different types, and with the suggestion that this period should be measured, not in days, but in terms of the inducement to evaporation, an effort is made to show, in Table 30, the total probable evaporation for each such period.

TABLE 30.—*Probable total evaporation during the period in which the mean soil temperature, for decades, at a depth of 1 foot, is below 32° F.*

[The letter F in decade spaces indicates periods when soil is commonly frozen.]

Station No.	Type.	Decade.	Cubic centimeters per 100 square centimeters.								Total for frozen period.
			Jan.	Feb.	Mar.	Apr.	May–Sept.	Oct.	Nov.	Dec.	
F-1	Control	1	F.	F.	.....	.....	.....	.....	.....	.....	.....
		2	F.	F.	.....	.....	.....	.....	.....	F.	.....
		3	F.	.....	.....	.....	.....	.....	.....	F.	.....
		Month.	139.8	78.3	.....	.....	.....	.....	.....	99.6	317.7
H-2	Sand hills	1	.....	F.	F.	.....	.....	.....	.....	.....	.....
		2	F.	F.	.....	.....	.....	.....	.....	.....	.....
		3	F.	F.	.....	.....	.....	.....	.....	.....	.....
		Month.	25.3	78.6	40.4	.....	.....	.....	.....	.....	144.3
M-1	Western yellow pine.	1	.....	F.	.....	.....	.....	.....	.....	.....	.....
		2	F.	.....	.....	.....	.....	.....	.....	.....	.....
		3	F.	.....	.....	.....	.....	.....	.....	.....	.....
		Month.	103.2	45.4	.....	.....	.....	.....	.....	.....	148.6
F-2	do	1	F.	.....	.....	.....	.....	.....	.....	.....	.....
		2	F.	.....	.....	.....	.....	.....	.....	.....	.....
		3	.....	.....	.....	.....	.....	.....	.....	.....	.....
		Month.	63.8	.....	.....	.....	.....	.....	.....	.....	63.8
F-12	do	1	F.	F.	F.	.....	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	.....	.....	.....	.....	.....	F.	.....
		Month.	81.2	110.3	98.5	.....	.....	.....	.....	53.7	343.7
F-4	Pine-fir	1	F.	F.	F.	.....	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	.....	.....	.....	.....	.....	F.	.....
		Month.	43.4	57.9	66.1	.....	.....	.....	.....	50.0	217.4
W-A2	Douglas fir, south	1	F.	F.	F.	.....	.....	.....	.....	.....	.....
		2	F.	F.	.....	.....	.....	.....	.....	.....	.....
		3	F.	F.	.....	.....	.....	.....	.....	.....	.....
		Month.	49.0	71.8	32.7	.....	.....	.....	.....	.....	153.5
F-7-8	Douglas fir, north, open.	1	F.	F.	F.	.....	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	F.	F.	.....
		3	F.	F.	F.	.....	.....	.....	F.	F.	.....
		Month.	57.3	55.2	104.2	.....	.....	.....	39.2	41.2	297.1
F-9	Douglas fir, north	1	F.	F.	F.	F.	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	F.	.....	.....	.....	.....	F.	.....
		Month.	19.6	23.4	28.1	15.4	.....	.....	.....	30.9	117.4
W-A1	do	1	F.	F.	F.	F.	.....	.....	F.	F.	.....
		2	F.	F.	F.	F.	.....	.....	F.	F.	.....
		3	F.	F.	F.	.....	.....	.....	F.	F.	.....
		Month.	11.2	19.3	66.2	65.6	.....	.....	25.2	7.4	194.9
F-11	Lodgepole	1	F.	F.	F.	F.	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	F.	.....	.....	.....	.....	F.	.....
		Month.	22.4	15.2	46.2	41.0	.....	.....	.....	45.6	170.4
F-6	Limber pine, northwest slope.	1	F.	F.	F.	.....	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	F.	.....	.....	.....	.....	F.	.....
		Month.	69.9	67.6	92.3	.....	.....	.....	.....	82.6	312.4
F-13	Limber pine, high ridge.	1	F.	F.	F.	.....	.....	.....	.....	F.	.....
		2	F.	F.	.....	.....	.....	.....	F.	F.	.....
		3	F.	F.	F.	.....	.....	.....	F.	F.	.....
		Month.	271.5	[1] 206.9	[1] 172.1	.....	.....	.....	112.3	133.9	796.7

[1] Relative evaporation for these months estimated at 150 per cent and 130 per cent, respectively, of that at the control station, as no record is available.

TABLE 30.—*Probable total evaporation during the period in which the mean soil temperature, for decades, at a depth of 1 foot, is below 32° F.*—Continued.

Station No.	Type.	Decade.	Cubic centimeters, per 100 square centimeters.								Total for frozen period.
			Jan.	Feb.	Mar.	Apr.	May-Sept.	Oct.	Nov.	Dec.	
F-3	Canyon spruce	1	F.	F.	F.	.....	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	F.	.....	.....	.....	F.	F.	.....
		Month.	9.8	5.5	30.1	.....	.....	.....	7.2	7.4	60.0
F-5	do	1	F.	F.	F.	F.	.....	.....	.....	F.	.....
		2	F.	F.	F.	.....	.....	.....	.....	F.	.....
		3	F.	F.	F.	.....	.....	.....	.....	F.	.....
		Month.	36.4	41.4	56.2	14.4	.....	.....	.....	25.0	173.4
W-D	High spruce, burn.	1	F.	F.	F.	F.	.....	.....	.....	F.	.....
		2	F.	F.	F.	F.	.....	.....	.....	F.	.....
		3	F.	F.	F.	.....	.....	.....	F.	F.	.....
		Month.	64.4	102.0	104.2	49.5	.....	.....	23.5	60.4	404.0
F-16	Pikes Peak, timberline.	1	F.	F.	F.	F.	.....	.....	F.	F.	.....
		2	F.	F.	F.	F.	.....	.....	F.	F.	.....
		3	F.	F.	F.	F.	.....	F.	F.	F.	.....
		Month.	23.8	13.8	40.1	62.6	.....	90.6	141.5	44.2	416.6

These data are based on (1) the period, by decades, in which the mean soil temperature is below 32°, the recorded temperature being corrected by one-half the amount indicated in Table 24, and each such decade being shown in Table 30 by a letter F; (2) the relative evaporation by months, for the particular station, as shown by Table 23; (3) the average evaporation for any decade or month at the control station, as shown by Table 22. The result, of course, is the merest approximation to the probable evaporation stresses of the average season, and does not indicate at all the extreme conditions that might be met. In a consideration of these data the fact should be borne in mind that at most of the local stations evaporation has been recorded 7 to 12 inches above the ground surface, but at others the height of instruments has been 5 to 20 feet. (See Table 23.)

Table 30 is based on so many assumptions that it can not be taken as conclusive, yet in a broad way its indications are felt to be important and valuable. The general effect of using the mean soil temperatures for several years is probably to make the period of soil freezing appear longer than it actually is in the average individual year. This is shown by using the actual data for the season of 1919–20, when a good many evaporimeters were in operation. At a well insolated station like the control the soil temperatures in a single season are found to consist of several depressions well below the freezing point, with intervals in which the soil moisture is very evidently available. The maximum continuous stress, therefore, is here only one-third as great as indicated by Table 30, and probably in the most severe of winters it would not be more than one-half as great. On the other hand, even a small amount of shade seems to be sufficient to prevent the thawing of the soil on warm days. The use of the mean soil temperatures, rather than maxima, of course introduces another chance of prolonging the freezing period beyond its actual limits.

Both the possibility of occasional thawing on well-insolated sites (that is, maxima above 32°) to a depth of 1 foot, and the probability that on such sites moisture nearer to the surface will be frequently

available, are seen by considering even a few original observations. For example, in a yellow pine site at Fremont, which has a very slight tilt to the south, and averages 1° to 2° cooler than the control station because of shading, while the soil temperature, as recorded at 8 a. m., was continuously below 32° from November 28, 1920, to February 27, 1921, a period of 91 days, there was during this period only one decade in December and one in February in which no surface temperatures above 32° were recorded at 8 a. m. Nor does this by any means speak for the highest temperatures of the day; and even the two exceptional decades showed maximum air temperatures above 40°.

The conclusion is inevitable, therefore, that the evaporation stress during periods in which soil moisture is completely nonavailable is far less for well-insolated sites than is indicated by Table 30. On the other hand, a continuously frozen soil, not only for the average, but in each individual year, is a practical certainty on every north slope and even in the canyon bottoms, which might be reached by the sun, but where the summer moisture supply is adequate to develop very dense stands. Table 30 may possibly exaggerate the evaporation stress by prolonging the period a little after the time when snow melting is rapid enough to provide the surface roots with water, but this very melting greatly retards the warming of the deeper soil. This difference between insolated sites which generally produce open stands and cooler sites which encourage denser stands must be further accentuated when it is considered that the evaporation measurements have nearly all been taken close to the ground. On a warm site the evaporation is likely to be little, if any, higher at a considerable elevation than near the ground. This is true not only because the open forest permits very good air circulation at all levels, but also because, in the winter period, radiation close to the ground may frequently cause thawing which would not otherwise be possible, and this will be an important element in the total evaporation. On the contrary, it is self-evident that in a close stand, the higher the elevation in the midst of the crowns, the greater will be both the insolation and the wind movement. The evaporation at the ground, therefore, is no measure at all of the stresses to which the more exposed crowns are subjected.

With the quantities shown by Table 30 as a guide, then, but with the factors which influence the relative values taken into consideration, the following observations may be safely made:

(1) The evaporation stresses to which seedlings may be subjected in a dense forest, even in a region of high winter-sunshine percentages, are appreciable for the total period of soil freezing, but undoubtedly become wholly insignificant with a snow blanket. On the other hand, the dense forest, as it commonly is on a slope facing the north, creates for its larger and more exposed trees a winter drought of long duration coupled with considerable evaporation stress. It is believed that the capacity for resisting the consequent drying out is, perhaps, a better measure of drought resistance than any ability which has, in the course of this study, been shown during warmer periods, because no severe summer drought has been encountered. The winter drought, as it affects the older trees in a dense stand, not only is of yearly occurrence, but seems to be almost independent of precipitation, except as the presence of a general snow blanket may increase the atmospheric humidity.

The trees which tolerate or in fact thrive under such conditions in this region are spruce and Douglas fir—the so-called "shade-tolerant" species. It is too early to draw a clear line between the two, although it is believed that the spruce is the more resistant of the two. To these conditions yellow pine is plainly unadapted, but limber pine fits in moderately well.

Thus, for the first few years in the life of the trees on the sites which produce the very dense forest, the conditions may give almost equal encouragement to several species. Although dense shade is more favorable to the tolerant spruce, Douglas fir and even the pines may become established because of deeper rooting and more ready adaptability to surface drought. On the other hand, when the trees begin to be exposed above the snow blanket, and the moisture supply is no longer controlled by depth of root, the struggle becomes almost altogether one of resistance to long-continued drying. The evidence presented in the paper on "Physiological Requirements of Rocky Mountain Trees," (*6*) which tends to show the greater photosynthetic activity of spruce, and which suggests that a high osmotic pressure is more normal in that species and, hence, less likely to be injurious, is applicable in this connection. This species which carries a dense sap, especially in a limited light, not only begins to resist evaporation earlier, but is least liable to injury should drying with all species be carried to the same point.

It is therefore believed that the struggle which determines the composition of the forest may continue long after the seedling stage is passed. The evidence, which has already been used more or less, indicates that on north slopes at middle elevations the original forest may be largely of Douglas fir, with considerable pine; but that in the second generation, from the sapling stage upward, spruce predominates, and must therefore form the climax.

(2) That the spruce forest is subjected to, or that spruce may tolerate, winter evaporation stresses of great magnitude is shown by the high spruce burn (W-D) and timberline stations. In neither place can there be much question that the soil freezing is severe and continuous, with no chance for even surface melting. The quantities indicated—around 400 grams of evaporation—are probably more nearly correct than any others that can be given, and must represent the approximate limit of resistance in plant growth. It must, however, be conceded that, after a certain amount of drying of the leaves has occurred, the process is halted until the atmospheric conditions become more severe (warmer or dryer, or both), so that beyond a certain time mere continuance of the stress does not comprise an endurance test.

The fact that both limber pine and bristlecone pine follow spruce nearly to the most exposed of its habitats seems to indicate either that the long exposure, as has just been depicted, is not so severe as it seems, or that these species possess a phenomenal ability to resist transpiration. The sum of the evidence necessitates falling back on the belief that neither of the pines occurs where the long winter drought, which is possible at a high elevation, is entirely unbroken. This is certainly the explanation of the conditions recorded on the high ridge (F–13). Moreover, this record is open to serious question from two angles.

(3) The considerably higher winter evaporation at the Wagon Wheel Gap stations, as compared with similarly situated ones at

Fremont, is not without its significance. (Compare W-A1 with F-9, W-A2 with F-2.) It is due both to a drier atmosphere and to greater prolongation of the soil freezing as a result of lower temperatures at Wagon Wheel Gap. Although the forest conditions at the north-slope stations are not dissimilar in the two localities, it is believed to be true, generally speaking, that both spruce and fir are pushed to somewhat lower levels in the Wagon Wheel Gap locality. On the south exposures, there is at Fremont a yellow pine forest with conditions slightly encouraging Douglas fir, and at Wagon Wheel Gap, a Douglas fir forest with considerable bristlecone pine of all ages. It is believed that the generally lower temperatures at Wagon Wheel Gap would not alone explain the complete absence of yellow pine, but that the greater possibility of destructive winter evaporation does explain it in part.

(4) Examination of the data for yellow pine sites, in the light of what has been shown as to probabilities of relief through frequent thawing, indicates that this species thrives best where the danger of winter drying is least. There is a slight suggestion that the lower limit, as approached at Station M-1, may be reached through an increase in this risk; but there is insufficient data on the plains conditions to justify this statement. It is known that the level plains freeze for considerable periods,[9] and that during such periods the evaporation may be relatively high; but as to the severity of this combination no estimate can as yet be made. It is evident that the Nebraska sandhills are not extraordinarily severe in this respect, and there is no evidence of winter killing in the established yellow pine plantations there. Stations F–12 and F–4 both appear to represent conditions which, as a result largely of the shade cast by the pine trees themselves, are approaching too great severity for the reproduction of that species.

The importance of this factor of winter evaporation with reference to yellow pine is clearly shown by the frequency with which pine forests in various parts of the range are injured by winter killing, which is rarely "killing" except to the foilage, but must detract greatly from the vitality of the trees affected and ultimately decrease their chances for predominance. It has been seen currently that the very lowest evaporation stress occurs on an open, smooth, southerly slope (F-2), and under these conditions the stand is almost pure yellow pine. It is significant that on other parts of this slope and on other similar slopes, which are strewn with boulders, a great deal more injury from winter drying has been noted; and that all such boulder-strewn areas develop a large proportion of Douglas fir, which is less seriously injured than is the western yellow pine.

To sum up: Successively lower temperatures in the types from pine to spruce, particularly well measured by the soil temperatures which show the effects of insolation or its lack, lead to more continuous, more severe, and more certain periods of soil freezing each winter. Consequently, other conditions being at all equal, the fully exposed trees growing on the coldest sites or in the coldest types are most liable to a winter drying so extensive as to be injurious to the trees and probably to affect the composition of the forest. Exactly the reverse is likely to be true with respect to conditions affecting young seedlings small enough to be protected by the snow blanket. Al-

[9] At Laramie, Wyo., the soil temperature at a depth of 3 feet is normally below freezing for 3 months, January to March.

though low temperatures tend to prolong the drought, they are usually conducive to the conservation of moisture in summer, and to the production of dense forests in which the individuals to some extent mutually protect each other from drying. Low air temperatures and high humidity reduce the relative drying power of the atmosphere and limit the extent of drying of the foliage. This may be more decisive than the duration of the drying or the possible amount of drying as indicated by an instrument which does not progressively increase its resistance. The physiological data, however, have indicated that the greatest degree of desiccation occurs in spruce in its coldest habitats.

Because of the many factors complicating the situation, both as to the actuality of complete freezing in the soil, and as to the stress to which the tree is being subjected, only the most direct and thorough measurements of both soil and atmospheric conditions can be entirely convincing. It is believed, however, that the factors have been sufficiently weighed to make it safe to say that spruce in the Rocky Mountains is subjected to winter drying of a degree and duration which would be quickly fatal to yellow pine. The importance of this factor with yellow pine, the writer is convinced, can not be overdrawn. It is only to be hoped that no error has been made in assuming that the other species, which less frequently show winter injury, are nevertheless susceptible in a degree, and that their distribution is affected thereby. As these drought conditions, however, result indirectly from and are so much involved with temperatures, it is still possible that temperatures in their growing-season relations control more definitely the composition of the forest types.

Surface temperatures.—It has been indicated that the soil temperatures at a depth of one foot bring out more fully than do the air temperatures the contrasts between sites which result primarily from differences in insolation and secondarily from differences in the densities of the stands, and the possible consequences of a marked cooling of the soil have just been depicted. There must remain, however, some question as to whether the critical effects of the temperature differences are felt more keenly in the winter than in the summer. It may, perhaps, clarify the situation and at the same time offer an explanation of certain successional changes if the statement is repeated that except in the typical, open and unblanketed yellow pine sites the effect of severe soil freezing can hardly be felt until the seedling has developed considerable height, and is then probably felt increasingly as the tree assumes a more exposed position. Whatever influence may be expected from surface temperatures on the contrary and from certain degrees of surface drying which must accompany them, is the influence exerted upon very young seedlings. The experience of planting shows conclusively that trees 3 or 4 years old are often immune to what are conceived to be the critical surface conditions.

As just suggested, extremely high surface temperatures may be directly fatal, or the extreme dryness resulting from superheating of the soil may tend to desiccate young trees, even though the roots are adequately supplied with moisture. As the direct or indirect influences of high temperatures are necessary concomitants, it is probable that injuries in both ways often occur concurrently. Even in closely controlled experiments, it will always be difficult to determine whether injury to seedlings is the direct result of superheating

and coagulation of the protoplasm, or results primarily from an excessive transpiration rate induced by the high temperature.

In "Physiological Requirements of Rocky Mountain Trees" (*6*) the results of a heating experiment are reported, which show that seedlings of Douglas fir and yellow pine, on the one hand, are relatively much more resistant to this form of injury than the seedlings of Engelmann spruce and lodgepole pine. In this test superheating was induced by direct sunlight in a warm greenhouse, and the high temperatures were usually maintained for several hours each day. A temperature of about 130° F, as measured by a blackened thermometer laid on the surface of the soil, appeared to represent the critical point. The form of injury was invariably wilting, first shown by the collapse of the stem of the seedling at the ground-line. In view of the fact that the pans containing the wettest soil showed little injury, the conclusion can hardly be avoided that in this test excessive transpiration and to some extent desiccation of the soil surface and of the stems at this level, were the primary causes of injury. Therefore, yellow pine and Douglas fir seedlings withstood injury because they are stouter and more deeply rooted than spruce and lodgepole pine seedlings of the same age.

Illustrating the complexity of the problem that is encountered when the effects of surface temperatures in the field must be noted, a more recent test may be cited.[10] In this test very high temperatures were secured by placing the pots of seedlings in close proximity to an electric heating coil with its radiation of long wave length. With exposures of about 10 minutes, little or no injury was shown until the pots were brought close enough to the coil so that a temperature of 140° F. was recorded by a thermometer at the level of the cotyledons. Temperatures as high as 130° F. could be endured for much longer periods without marked injury. It therefore appears that a temperature of 140° F. or slightly higher, is directly injurious in a period too short to permit much transpiration loss. Under these conditions the cotyledons of Douglas fir shriveled markedly, and usually with fatal results to the entire seedling; yellow pine seedlings were next in order, but the injury was usually localized in portions of the leaves, and not so likely to be fatal; spruce seedlings shriveled completely, like those of Douglas fir, but much less frequently; within the range of the tests lodgepole pine seedlings were practically immune to this heat injury.

With this view of the problem, and a realization of its intricacy and the need for most careful and complete field records, there can be but one object in introducing the available data on the surface temperatures of sites in the Pikes Peak region, namely to show the magnitude of the variations in surface temperatures, as compared with the variations in the temperatures at a depth of 1 foot. After considering these few data, and the facts which have been stated above relative to the resistance of the several species to direct and indirect heat influences, it will be apparent that while high temperatures bring out a nice distinction between yellow pine and Douglas fir, the line between fir and spruce is probably drawn on a different basis, most probably on the basis of the moisture relations alone.

The determination of the exact temperature of the surface soil, during insolation, is next to impossible. It is practically possible

[10] U. S. Dept. Bul. 1263, Relative Resistance of Tree Seedlings to Excessive Heat.

only to determine the temperature of some object lying on the surface, exposed to the same insolation as the surface and presumably absorbing somewhat the same amount of the radiant energy. In this study the Freiz soil thermograph has been used, the bulb (1 inch in diameter by about 12 inches long) being laid up and down the slope and being about half imbedded in the surface material. Corrections for the thermograph readings have been secured by exposing mercurial thermometers in the same way the thermograph bulbs were exposed. Frequent readings have been made when both thermograph and thermometer would be affected mainly by the soil with which they were in contact. The temperatures, therefore, at correction points, are considerably below the maxima secured in sunlight, and this introduces another possible source of error when the maxima of the thermographs are used. The observations in 1920 extended from May to September, inclusive; but, as the July temperatures were greatly in excess of those for other months, only these need be considered. (Table 31.) It is possible, with the corrections obtained through the 5 months' period, to estimate the maxima from the thermograph traces very closely, except in the record for Station F–5, where the instrument behaved very erratically.

TABLE 31.—*Soil temperatures in July, 1920, in degrees Fahrenheit.*

[Numbers in parenthesis indicate the decade or day of month in which maxima occurred.]

Station No.	Type.	Maximum surface temperatures.		
		Monthly mean.	Highest decade.	Highest day.
F–12	Western yellow pine ridge	112.57	119.97 (1)	130.6 (22)
F–4	Pine-fir east slope	116.68	124.75 (1)	142.7 (23)
F–6	Limber pine northwest slope	94.45	98.81 (1)	126.5 (2)
F–5?	Spruce bottom	84.24	89.71 (2)	110.5 (2)

Even though these data do not cover a great variety of conditions, it is possible to make certain generalizations, which at least indicate the importance of the maximum temperatures attained by the soil surface.

(1) The extreme temperatures which may be expected at the surface of the soil vary, as between differently insolated sites, by three to four times as wide a margin as do the corresponding 1-foot soil temperatures. For example, the mean July temperature for Station F–5 (Table 27) is 49.0°, and for Station F–12 is 58.3°, a difference of 9.3°; but the difference in their surface temperatures is 28.3°. It is thus seen that the surface temperatures are needed to give an adequate idea of the possible effects of direct insolation.

(2) In this locality it seems that an east exposure may be liable to greater extremes of temperature than a flat or slightly southerly exposure, simply because of the normal tendency of clouds to accumulate as the day advances. Thus the month in question gave 8,336 minutes of sunshine before noon, and only 3,027 after noon, the hours from 7 to 10 a. m. being about 88 per cent clear. Likewise,

a west exposure is frequently prevented from reaching a high surface temperature; but, if sunshine continues all day, its temperature, as a natural consequence, may be very high after the air has become well warmed.

SUNSHINE.

Since the control station was established in 1910 the duration of sunshine has been measured there by means of the standard Weather Bureau electric-thermometric recorder. At stations in the various forest types it has not been measured long enough to give records of much value. Hence it is believed that, in comparing the types, the indirect evidences of insolation may perhaps be more useful, though it is not desirable to reach any such decision without exhaustive trial. In short, then, the available record is only for the control station, which gives a measure of sunshine values for the general locality at a middle elevation, and for a similar period at Wagon Wheel Gap. These data are valuable in the general study of the climate, and currently in studying such other phenomena as soil temperatures. They may prevent reaching wrong conclusions as to the import of other factors.

Sunshine at the control station.—This record is made up wholly from the graph written by the pen of the triple register, with almost no interpolation, and without the additions which are termed "twilight corrections," and which are sometimes employed to compensate for the lag in the response of the recorder—or, perhaps it might better be said, its lack of response—when the sun is very close to the horizon. The study has not been intensive enough to permit the application of such corrections, although it may be roughly estimated that they would add, on the average, 30 minutes each day to the duration of sunshine, increasing the yearly average by 11,000 minutes or about 5 per cent of the possible. Because of the failure to apply these corrections, the record is not strictly comparable with the Wagon Wheel Gap record or with Weather Bureau records in general.

The possible duration of sunshine at the point where the recorder has been located was determined by observations of sunrise and sunset at that point on almost every clear day during 1910 and 1911. By plotting these hours, the length of each day, decade, and month was computed. The day at this location is considerably shorter than it would be on a plain in the same latitude, as the sun sets at an elevation of nearly 10°, and on the longest days also appears first at a slight elevation.

The basis at Wagon Wheel Gap is the same, namely, short days caused by a high horizon to the west, which on the average shortens the day by more than two hours. Here, however, closer observation has permitted twilight corrections.

In Table 32, the actual sunshine for each decade of record is shown, together with the mean for each decade and the percentage relation of this mean to the possible. It is desirable to call attention to the fact that the records of the last two years have very materially altered the averages, especially for May and June.

TABLE 32.—*Total minutes of sunshine at the control station (F–1).*

[Height of instrument above ground, 22 feet.]

Year.	Decade.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total annual.	Total growing season.
1910	1	.....	3,377	5,020	4,718	4,314	6,255	5,747	3,402	5,856	4,790	2,434	2,248	.....	.....
	2	.....	3,383	4,756	4,424	4,190	6,615	4,741	4,419	3,271	3,370	593	3,215	.....	.....
	3	.....	3,567	6,261	4,992	5,379	5,841	5,447	5,239	4,391	4,356	2,823	4,479	.....	.....
	Month.	.....	10,327	16,037	14,134	13,883	18,711	15,935	13,060	13,518	12,516	5,850	9,942	[1] 157,451	53,562
1911	1	4,436	4,739	5,358	5,825	5,944	7,132	5,922	4,845	3,663	3,955	2,864	4,307	.....	.....
	2	4,654	4,263	4,907	6,173	6,160	5,726	6,655	2,831	3,913	3,857	2,947	3,026	.....	.....
	3	4,448	3,998	6,051	4,992	6,318	7,043	5,585	3,083	3,007	2,674	3,746	4,406	.....	.....
	Month.	13,538	13,000	16,316	16,990	18,422	19,901	18,162	10,759	10,583	10,486	9,557	11,739	169,453	52,485
1912	1	4,722	4,401	5,371	6,256	5,686	5,509	6,611	5,551	5,565	3,795	3,734	3,768	.....	.....
	2	4,506	4,399	5,478	5,636	5,387	4,634	4,977	4,469	3,065	5,087	4,087	3,871	.....	.....
	3	5,363	4,225	6,227	6,261	7,602	6,119	5,192	6,082	3,753	3,904	3,353	3,586	.....	.....
	Month.	14,591	13,025	17,076	18,153	18,675	16,262	16,780	16,102	12,383	12,786	11,174	11,225	178,182	54,709
1913	1	2,654	3,354	4,409	2,842	3,178	2,145	5,004	4,569	3,219	2,704	4,048	[2] 3,150	.....	.....
	2	3,627	3,223	3,286	4,773	3,985	3,686	3,812	3,357	3,294	1,629	3,350	[2] 3,300	.....	.....
	3	3,753	2,762	4,150	3,572	5,442	5,134	4,844	3,787	1,568	3,330	2,927	3,673	.....	.....
	Month.	10,034	9,339	11,845	11,187	12,605	10,965	13,660	11,713	8,081	7,663	10,325	10,123	127,540	39,557
1914	1	3,095	.....	.....	2,436	4,404	4,959	[3] 3,767	2,506	3,636	5,417	5,359	3,212	.....	.....
	2	3,417	.....	.....	4,115	2,113	4,422	2,947	3,860	3,599	5,125	4,585	.....	.....	.....
	3	.....	.....	.....	2,604	5,311	6,166	2,905	2,822	3,837	4,997	4,503	.....	.....	.....
	Month.	.....	.....	.....	9,155	11,828	15,547	9,619	9,188	11,072	15,539	14,447	.....	.....	37,900
1915	1	.....	.....	2,753	3,499	3,687	3,978	5,144	3,646	4,020	4,794	3,491	3,448	.....	.....
	2	.....	.....	3,132	2,404	4,360	5,651	4,437	4,062	4,764	3,136	3,717	3,514	.....	.....
	3	.....	.....	3,435	3,362	4,548	3,884	4,203	4,712	3,961	5,363	3,825	3,020	.....	.....
	Month.	.....	.....	9,320	9,265	12,595	13,513	13,784	12,420	12,745	13,293	11,033	9,982	.....	43,737
1916	1	3,802	4,232	4,140	3,937	5,611	4,358	5,273	4,474	4,560	3,690	4,460	3,625	.....	.....
	2	2,405	4,828	5,088	4,012	3,425	4,936	4,311	3,286	3,537	2,132	3,528	2,992	.....	.....
	3	3,190	4,121	4,454	2,509	6,752	6,039	3,756	3,629	3,777	5,018	4,269	4,170	.....	.....
	Month.	9,397	13,181	13,682	10,458	15,788	15,333	13,340	11,389	11,874	10,840	12,257	10,787	148,326	41,622

1917	1	4,196	4,353	4,162	4,900	2,745	5,159	3,983	3,888	3,321	4,253	4,552	3,177	.....	.....
	2	3,480	3,417	4,975	3,754	4,026	5,279	4,229	2,647	3,212	3,725	3,349	3,903	.....	.....
	3	4,601	2,841	5,419	3,692	1,851	5,369	4,720	3,964	3,909	2,613	3,431	4,144	.....	.....
	Month.	12,277	10,611	14,556	12,346	8,622	15,807	12,932	10,499	10,442	10,591	11,332	11,224	141,239	42,559
1918	1	3,175	4,568	5,067	2,611	3,912	2,897	2,660	3,109	1,866	.....	.....	.....	.....	.....
	2	2,759	4,605	5,366	2,768	4,655	3,730	2,820	3,730	3,218	.....	.....	.....	.....	.....
	3	3,747	3,153	4,840	4,402	2,478	3,673	4,510	4,182	.....	.....	.....	.....	.....	.....
	Month.	9,681	12,326	15,273	9,781	11,045	10,300	9,990	11,021	.....	.....	.....	.....	.....	33,177
1919	1	.....	.....	.....	.....	2,596	1,611	4,578	3,881	3,635	3,339	3,449	3,363	.....	.....
	2	.....	.....	.....	.....	3,368	3,797	3,770	5,491	2,860	3,357	4,020	4,063	.....	.....
	3	.....	.....	.....	.....	4,215	4,689	4,818	4,735	4,558	4,418	3,121	4,586	.....	.....
	Month.	.....	.....	.....	.....	10,179	10,097	13,166	14,017	10,853	11,114	10,590	12,012	.....	40,915
1920	1	2,991	3,573	3,585	4,663	3,181	2,821	3,671	3,648	2,888	3,783	2,238	2,945	.....	.....
	2	3,923	4,598	5,024	3,549	2,331	3,112	3,678	3,325	4,227	3,783	2,409	2,596	.....	.....
	3	4,475	3,341	5,299	4,002	4,086	2,970	4,014	4,731	4,580	2,876	3,094	2,577	.....	.....
	Month.	11,389	11,512	13,908	12,214	9,598	8,903	11,363	11,704	11,695	10,442	7,741	8,118	128,587	34,858
1921	1	3,163	3,147	3,412	4,201	4,655	2,744	5,274	.....	.....	.....	.....	.....	.....	.....
	2	3,401	4,096	4,069	3,947	3,471	4,171	5,490	.....	.....	.....	.....	.....	.....	.....
	3	3,944	3,925	4,457	4,691	5,395	4,448	6,933	.....	.....	.....	.....	.....	.....	.....
	Month.	10,508	11,168	11,938	12,839	13,521	11,363	17,697	.....	.....	.....	.....	.....	.....	.....
Average to July 31, 1921	1	3,582	3,972	4,328	4,172	4,159	4,131	4,803	3,956	3,839	4,052	3,663	3,324	.....	.....
	2	3,575	4,090	4,608	4,141	3,956	4,647	4,322	3,762	3,542	3,515	3,258	3,387	.....	.....
	3	4,190	3,548	5,059	4,098	4,948	5,115	4,744	4,270	3,734	3,955	3,509	3,849	.....	.....
	Month.	11,347	11,610	13,995	12,411	13,063	13,893	13,869	11,988	11,115	11,522	10,430	10,560	145,803	43,589
Mean per cent of possible.[3]	1	69	71	71	62	58	55	65	55	57	66	66	64	.....	.....
	2	68	71	74	60	55	62	58	54	54	59	60	66	.....	.....
	3	70	72	71	58	61	68	59	56	60	62	66	68	.....	.....
	Month.	69	71	72	60	58	62	61	55	57	62	64	66	62.6	59.0

[1] Twelve months to January, 1911.
[2] Decade value obtained by proportion, two to four days' record missing.
[3] Algebraic means derived from average figures above, for decades, months, growing-season, and year

TABLE 33.—*Distribution, by hours, of sunshine in representative decades at Station F–1.*

[Average, 1910–1918, inclusive.]

Period.	Sunshine duration in minutes.													
	For hour ending (a. m.)—							For hour ending (p. m.)—						
	6	7	8	9	10	11	12 noon.	1	2	3	4	5	6	7
First decade, March	.....	2.5	28.9	46.7	53.7	53.8	53.3	54.8	51.4	47.7	43.7	18.9	.....	.....
Last, June	1.6	42.7	52.1	52.5	52.9	51.8	51	48.6	42.5	38.8	37.8	35.4	30.3	6.6
Middle, August	.....	18.9	44.6	51.8	49.5	41.9	33.7	28.6	26.6	21.9	17.1	16.8	11.6	.3
Third decade, April	.....	19	37.6	39	42.3	44	42.3	40.5	40.4	36	27.1	22.7	13.2	.2

To show more clearly the immediate causes for high and low sunshine percentages, there are given in Table 33 and Figure 9 the distribution of sunlight by hours for representative decades.

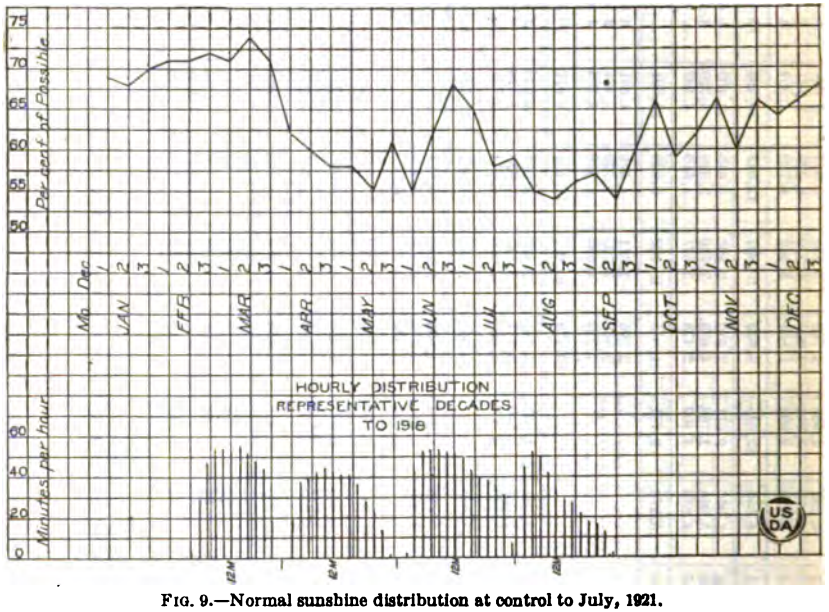

FIG. 9.—Normal sunshine distribution at control to July, 1921.

The first three months of the year, when anticyclonic winds prevail, are characterized by high percentages of sunshine, which reach a climax at the middle of March. After this, as storm centers move eastward in a more northerly path, the humidity of the air is greatly increased, and this makes itself felt in a great deal of foggy weather in April or May, accompanied by much snow or rain. In general, a tendency is noted for the fog to be dissipated in the middle of the day. The control station is at such an elevation as to be frequently engulfed by the clouds which hang over the plains country, while above this elevation it may be clear. Or, again, it may be clear over the plains, but the rising air currents during the day induce the formation of clouds over the mountains.

As the storm centers move farther north, this locality is characterized again by dry weather, which reaches a culmination at the end of June, after which time the summer rains begin. Although the

air movements at midsummer are influenced by the position of the continental low-pressure area, the phenomenon of clouds is really a local one, and those that form about Pikes Peak are the result of daily convectional currents. Soon after noon precipitation is likely to occur, and this so cools the ground that convection ceases; the rest of the day is often but not regularly clear. This phenomenon is of interest in that an easterly slope during this period may receive almost as much insolation as a south slope. The autumn is characterized by gradually decreasing cloudiness, but this is interrupted by storm periods about the middle of each fall month. This apparent regularity of the storm periods would probably disappear with a longer record, although the mid-September storm is considered typical of the whole region and usually brings the first snow.

Comparative sunshine in central and southern Colorado.—In Table 34 the mean sunshine percentages are shown for the Fremont and Wagon Wheel Gap stations. The record for the latter is brought up to October, 1920.

TABLE 34.—*Sunshine at Fremont and Wagon Wheel Gap stations.*

Station.	Elevation.	Percentages of the possible, by months.												Year.	Growing season.
		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.		
	Feet.														
Fremont (F-1)	8,836	69	71	72	60	58	62	61	55	57	62	64	66	63	59
Wagon Wheel Gap (W-C)	9,237	57	59	58	52	55	56	44	48	52	59	61	57	55	50

The sunshine percentage at Wagon Wheel Gap approaches that at Fremont only in May, when the humidity is very low, and from September to November, when clear weather is characteristic of the Rocky Mountain region. The winter at Wagon Wheel Gap is characterized by much less sunshine and more precipitation. The depression is very great in July also, when the rainy season reaches its height, which is about a month earlier than at Fremont.

The general comparison indicates that the vicinity of Pikes Peak is one of high sunshine percentages, a condition which is of especial importance in the winter in facilitating evaporation. As we have seen, this influence on south exposures may be just about counterbalanced by the action of the sunlight in thawing the soil; but where the sunlight does not reach the ground its influence must be solely to increase transpiration.

PRECIPITATION.

Precipitation at the control station, by seasons.—The precipitation record for the control station is complete for the entire period of operation of the station, beginning with January, 1910, and ending with July 31, 1921. Although this record has been obtained as carefully as possible with the 8-inch standard gauge, supplemented by the tipping-bucket gauge during the open season of each year, it is considered to be, like all other precipitation records, only an approximate statement of conditions. Because of this general weakness, it has not been thought necessary to check up minor discrepancies which may

exist in the original tabulations of the data. A further reason for not attempting any high degree of precision in the record is the realization that the total precipitation can show only in the most general way the amount of water available for plant growth, as this amount will depend perhaps as much on soil properties as on water received.

TABLE 35.—*Monthly and annual precipitation at the control station, in inches.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total annual	Total growing season[1]
1910	0.01	0.44	0.51	1.18	2.56	1.89	4.47	3.27	1.01	0.86	0.53	0.61	17.34	9.97
1911	.06	1.56	1.67	2.20	.93	1.21	5.42	2.01	1.44	1.45	.61	1.13	19.69	9.12
1912	.06	1.12	.60	1.56	2.67	4.04	4.62	1.82	1.17	1.59	.17	.23	19.64	10.87
1913	.95	.99	1.04	2.06	1.76	3.91	2.18	3.92	3.32	1.06	.32	5.01	26.52	11.12
1914	[2].35	.....	.....	4.01	2.40	4.05	6.76	2.06	.23	1.98	.10	.....	.....	12.95
1915	.....	.....	1.66	3.53	3.43	3.09	2.12	4.78	2.18	.70	.37	.40	.....	10.74
1916	.40	.03	.97	4.54	1.99	1.83	4.72	3.11	.48	.54	.63	.40	19.64	9.82
1917	.25	1.08	1.83	1.77	3.77	.79	1.50	3.87	1.66	.26	.25	.18	17.21	6.71
1918	.96	.94	1.32	2.68	.52	3.70	3.13	3.32	.....	.....	.....	.....	.....	[3]11.42
1919	.....	.....	.....	.....	.49	.87	4.16	1.46	1.82	.75	.94	.24	.....	6.83
1920	.74	1.12	.39	1.86	[4]2.23	1.88	2.63	6.39	1.17	1.87	.27	.73	21.28	11.74
1921	1.27	.32	1.20	7.22	1.07	8.17	4.70	.....	.....	.....	.....	.....	.....	.....
Mean	.50	.84	1.12	2.96	1.98	2.95	3.87	3.27	1.45	1.11	.42	.99	21.46	10.57

[1] Prior to 1918 growing-season totals are obtained by using one-third the total for September; thereafter the actual amount September 1–10 is used.
[2] Based on 0.23 inch, January 1–20.
[3] Based on actual fall of 1.27 inches, September 1–10.

The complete record for the control station, by months, is shown in Table 35. In this, as in all the succeeding records, the total for the growing season has been obtained by adding to the amounts for June, July, and August one-third the total for September. In fact, the greater part of the September precipitation, or at least considerably more than one-third, belongs to the second decade; hence this computation is only an approximation to the truth.

Perhaps the most important thing shown by this table is that normally almost one-half of the total precipitation occurs during the growing season. In nine years the least amount in this 102-day period has been approximately 7 and the greatest 13 inches. To the 7 inches falling in 1917 there may be added, for all practical purposes, the 3.77 inches in May, which left the ground in a soaked condition up to June 5, and which materially assisted in tiding over the marked drought which followed that date. Notwithstanding this, however, the soil moisture at the end of the growing season reached a lower point than has been recorded in previous years, and it may safely be said that with less than this amount in the growing season there would be danger of drought conditions which might affect the composition of established stands. Unfortunately there were no soil-moisture measurements made in the dry summer of 1919.

In brief, then, the summer precipitation is ordinarily quite adequate to maintain the soil of the most exposed sites at this elevation in very good condition. The winter precipitation is very inadequate, either to protect the soil from severe freezing or to store up moisture for late spring use, except on north slopes and under dense stands. Probably there is about as much water here, in the form of snow to be melted in the spring, as the soil will hold within reach of the roots.

Although the individual years do not vary in precipitation much more widely than in other conditions, the months do. Thus a long record seems necessary to establish even an approximate "normal" precipitation for a given month. The addition of the 1918 record to the record for the eight preceding years created two new extremes, namely, a new high for January and a new low for May, and the growing-season total was the highest of record except for 1914. Again, the year 1921, through July, created three new monthly maxima, and the last 12 months of record show a total of 34.38 inches.

Comparative precipitation.—No serious effort has been made to compare the precipitation in the several forest types in the vicinity of the Fremont Station, for it has been assumed that, so far as topography might influence the actual fall, differences would be compensating over any long period. It is perfectly evident that one spot may at one time receive from summer rains much more moisture than another only a few hundred feet away, and such a variation may not be compensated for a long time. However, where the difference is marked, the excess at a given point is likely to be largely wasted in surface run-off.

From March, 1910, to February, 1912, at three stations within a radius of a few hundred feet gages were maintained on towers so situated that there was almost no interference by branches of trees, but with varying degrees of protection from wind. Table 36 gives the mean annual catches that were recorded.

TABLE 36.—*Precipitation catches at three stations, 1910–1912.*

Station No.	Type.	Mean annual precipitation.
		Inches.
F–1A	Control, open	19.25
F–2A	South-slope western yellow pine	18.95
F–3A	Canyon spruce	20.12

For the period April, 1916, to February, 1917, a gage on the ground at Station F–9, under dense cover of fir and spruce and less than half a mile from the control station, gave a catch of 22.73 inches as compared with 19.32 inches at the control station. The excess under canopy was very great from certain rains on account of some spruce branches, but with snow a deficit was generally created by these same branches. A very different result would doubtless have been obtained 2 feet farther from the tree whose branches most directly influenced the path of falling rain or snow.

If the amounts of snow on the ground in the different types are compared for the late spring period when such snow may represent an asset for the coming growing season, the greatest contrasts may be obtained. It is not the purpose of the writer to discuss this feature here. Moreover, because of lack of adequate data, it is not possible to give any numerical weight to the retained precipitation of the various forest types here studied. However, the data given in Table 37, reproduced from the preliminary report on this project, indicate the importance which must be attached to this subject in considering precipitation data.

TABLE 37.—*Snow on the ground under various conditions of exposure, winter 1910–11.*

[Mean snow depth, inches.]

Station No.	Type.	November.	December.	January.	February.	March.	April.	May.
F-1	Control, open ridge	0.2	0.6	0.1	3.5	1.1	0.6	0.0
F-2	South-slope western yellow pine	.2	.5	.1	3.5	1.6	.6	.0
F-3	Canyon spruce [1]	.5	1.5	.6	3.0	6.2	1.7	.0
W-C	Open east slope	4.1	10.4	20.0	20.3	26.1	9.2	.0
W-A1	North-slope Douglas fir	13.4	17.1	23.5	21.2	36.4	28.4	3.4
W-A2	South-slope Douglas fir	.6	4.2	5.0	.9	8.8	.1	.0
W-D	Higher spruce bench	11.8	16.9	24.6	24.5	44.5	36.3	13.8

[1] The ground is the lower edge of a northeasterly slope.

The precipitation in various forest types within the range of this study may now be considered, as shown in Table 38. For the control station the complete record to the end of 1917 is used. For other stations having an unbroken record from 1910 to 1917 the same months are eliminated as are missing from the record of the control station. When the compared record is considerably broken, all that is available is used.

In the Pikes Peak series (C–1, M–1, F–1, L–1) the seasonal variations are very similar to those at the control station. The total amount of precipitation for the year or any shorter period increases fairly regularly with increased elevation, except that in the step from the Plains type to the yellow pine type the increase is generally larger than elsewhere. This, it is thought, may be due to the exposure of the Plains station, which is nearly always subject to north and east winds during precipitation. These winds make it more difficult to secure a complete catch. The yellow pine type for almost the entire winter period, moreover, shows more precipitation than the much higher control station. No adequate explanation of this can be offered.

The yellow pine types of the Black Hills and of southern Colorado (D–1 and P–1, respectively), which support yellow pine stands of far better development than those of the Pikes Peak region, have the benefit of a much greater total precipitation; but this excess is almost wholly outside the growing season. It may be said that the heavier winter snows are of direct benefit to seedlings, and that they protect the older trees by preventing the freezing of the soil. If, however, the low rainfall in southern Colorado during April, May, and June is considered, it is readily seen, as has been pointed out by Pearson (*18*), that the moisture of winter snows may not hold over till summer and hence can not directly affect the rate of growth. In the Black Hills it probably does not hold over, but melts early at that low elevation, but the spring precipitation is itself abundant and undoubtedly is an important supplement to that of the growing season. Nevertheless, in the search for conditions which may influence the growth of all species probably none has been found which is more important than the winter deficit of precipitation in the Pikes Peak region, when considered in connection with high winds and atmospheric dryness.

One hundred miles farther north, in a similar topographic position (Station F–17), this winter deficit is far less apparent, though the high precipitation for this station may possibly be due to purely local conditions which encourage a transport of snow from the high hills round about.

TABLE 38.—*Precipitation, in inches, in various localities and forest types.*

[For the period of record at the control station between 1910 and 1917.]

Station No.	Type.	Locality.	Elevation.	Period.	Record by months.												Total annual.	Total growing season.[1]
					Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
			Feet.															
C-1	Plains	Pikes Peak	6,098	Same as F-1	0.16	0.80	0.56	2.30	1.90	1.98	2.83	1.88	0.79	0.46	0.17	0.56	[2]14.34	6.90
M-1	Western yellow pine.	do	7,200	1911–1917, 3 months missing.	.47	.92	.96	2.72	2.84	1.80	3.49	2.59	1.18	1.15	.53	1.24	19.89	8.27
D-1	do	Black Hills	4,535	Same as F-1[3]	1.04	1.22	2.99	3.50	3.56	2.97	2.60	2.72	2.21	2.31	1.00	1.38	27.50	9.03
P-1	do	Southern Colorado.	7,108	Jan., 1907, to Mar., 1917, 5 months missing.	2.72	1.94	1.80	1.90	1.08	1.12	3.20	2.61	1.88	3.36	1.08	1.74	24.38	7.54
F-1	Control	Pikes Peak	8,836	1910–1917[4]	.30	.87	1.18	2.61	2.44	2.60	3.97	3.10	1.44	1.06	.37	1.14	21.08	10.15
F-17	Douglas fir	Northern Colorado.	9,300	1910–1917, 4 months missing.	1.39	1.69	1.74	2.79	2.80	2.02	3.61	2.29	2.35	2.20	.91	2.44	26.23	8.70
W-A1	do	Rio Grande	[5]10,000	Nov., 1910, to Dec., 1917.	1.57	1.33	1.47	2.13	1.14	1.37	3.69	2.37	1.76	2.13	.94	1.40	21.30	8.02
L-1	Spruce	Pikes Peak	10,265	Same as F-1	.56	.96	1.49	2.95	2.64	2.72	4.67	3.79	1.37	1.50	.46	1.53	[6]24.64	11.64
W-F	do	Rio Grande	11,500	Nov., 1913, to Dec., 1917.	3.06	1.57	1.77	3.98	1.91	.73	4.00	2.37	1.88	2.42	1.61	2.69	27.99	7.73
L-2	Spruce-lodgepole	Continental Divide.	10,248	Same as F-1	1.66	1.13	1.09	1.43	1.32	1.27	1.33	1.56	1.22	1.40	.66	1.29	15.36	4.57
F-18	Lodgepole pine	Northern Colorado.	8,560	do	1.72	1.47	1.58	1.70	1.60	1.01	2.48	1.30	1.85	1.39	.85	2.05	19.00	5.41
N-1	do	Western slope	8,800	do	2.00	1.39	1.31	1.39	1.39	1.15	2.29	1.24	1.59	1.27	1.00	1.09	17.02	5.18
F-11	do	Southern Wyoming.	9,015	1910–1917, 16 months missing.	1.11	1.80	1.25	1.60	1.36	.98	1.47	1.21	1.62	.90	1.01	1.23	15.54	4.20

[1] Growing-season totals obtained by taking one-third the September amount.
[2] December, 1914, substituted for December, 1910.
[3] Normal to 1916, 14.59 inches.
[4] Except February, March, December, 1914, and January, February, 1915.
[5] Mean precipitation determined by gages at 9,600 and 10,900, the difference between the two averaging less than 1 inch per year.
[6] Normal, 22 years to 1916, 24.98 inches.

Somewhat similar conditions are noted at the middle elevation at Wagon Wheel Gap (Station W–A1). Here, however, as farther south, the marked deficit is in May and June. Although the winter precipitation as a whole is adequate, the amount in November and December is hardly sufficient, in connection with the sudden drop in air temperatures, to prevent deep freezing of the soil.

The spruce type in the Wagon Wheel Gap locality, the only one which we may compare with Station L–1 in the Pikes Peak series, does not show much more precipitation than the local station except during the winter, and is much more liable to drought during the summer. The Wagon Wheel Gap site produces a superior spruce forest, but its conditions are not more conducive to abundant reproduction.

The lodgepole types are all inferior to the control station in total precipitation, and only half as favorable in growing-season precipitation. All, however, secure a better snow blanket in the winter, not only because of larger snowfall, but because the snow is protected by low air temperatures. Frequently in lodgepole sites the ground is not exposed after the first heavy snow in September. It is seen, then, that lodgepole receives and thrives with less precipitation during the growing season than even yellow pine, but that, like yellow pine, it is surrounded by conditions conducive to the maintenance of an unfrozen or only slightly frozen soil during the winter.

SOIL MOISTURE.

When it is observed that losses by evaporation may be two or three times as great from one site as from another receiving the same precipitation, it is at once apparent that the record of precipitation is almost without value in indicating the moisture conditions under which the several species develop. If it is at all true that the amount of moisture available, or its degree of availability, appreciably influences the character of the plant formation, then an attempt should be made to measure the soil moisture as directly as possible. This should be done notwithstanding the fact that precipitation and evaporation rates, when considered together, constitute a valuable basis for comparing the moisture conditions of broad regions and the general types of their flora.

That the proper use of soil moisture data in a comparison of sites is by no means a simple matter becomes more apparent as the behavior of the soil solution is more exactly studied. In the "Research Methods in the Study of Forest Environment," (*24*) a serious effort has been made to depict the soil-moisture problem as it actually exists. In order that the viewpoint and treatment in that publication may be understood, it is sufficient to say that the soil solution is regarded as having osmotic properties similar to those of the plant solution, and that the osmotic pressure of the soil solution is always opposed to that pressure within the plant which gives rise to absorption by the plant (root) cells. If the plant pressure is increased by ordinary water loss through transpiration, or if the soil solution is diluted, the rate of absorption must increase. If the plant pressure is decreased or the soil pressure increased, the flow into the plant must be decreased, stopped, or even reversed.

At least a suggestion of this osmotic relation is contained in a statement by Livingston (*14*) as early as 1902, and a much clearer treatment of the subject has gradually evolved in numerous other papers. Livingston says:

> A strong solution will extract water from the organism, a weak one will allow it to be absorbed. * * * Change in the water content of the protoplasm may be directly effective by causing a change in its physical properties. For instance, if water is extracted, the viscosity of the protoplasm must be increased. The change in water content may result in a change in the chemical activity of the protoplasmic solution, since chemical activity, in general, depends upon the concentration of the solution involved. How it comes about is not known, but a review of the literature of experiments upon animals and plants shows that growth is very much retarded by an external solution which extracts water. Especially is the elongation of cells retarded.

Clements (*9*) describes this relation in discussing the plant (par. 60) but ignores it in the method of treating soil moisture control (par. 9).

The investigations of Bouyoucos (*8*) and Hoagland (*12*), especially, in more recent years, have created the conception of the soil solution as one exerting a definite osmotic pressure. This conception has been attained through the study of freezing points, and their correlation with concentration of the soil extract. In the "Research Methods in the Study of Forest Environment" evidence was introduced to show that the soil water exerts a definite vapor pressure.

With this light on the subject, it must be evident that the total quantity of water present in the soil has very little bearing on either growth or survival. The ability of the plant to obtain water in sufficient quantity to maintain life, or in sufficient quantity to maintain conditions favorable for metabolism and growth, must at all times depend primarily on the differential between the osmotic pressure exerted by the cell contents, and that which, for the sake of distinction, we may term the "antiosmotic pressure" of the soil water.

It is of course to be kept in mind that the osmotic pressure of the plant cells is not stable. If atmospheric conditions create a heavy loss by transpiration, and thereby create a great need for water in the plant, it follows that the ability of the plant to extract the water from the soil is automatically increased, by reason of increased osmotic pressure in the cells. It does not follow that this increase in pressure will immediately insure all that is needed. Hence, if the demand is very great or arises too suddenly, there may be wilting; and, if it is too long continued, there may be permanent injury.

Unfortunately the treatment of the soil solution as one exhibiting or following the laws of osmosis is not entirely simple, because, although its properties are primarily determined by the solutes present, they are also affected at all stages by the solid particles and colloidal masses of the soil, whose affinity for liquid water has the same effect on the activity of the water molecules as has the affinity of solids in solution. The critical point, however, is this, that while there is still some water in the soil—sometimes 10 per cent or more—it may be so completely and effectively held in thin films or small aggregates by the soil solids, that the water entirely loses its properties as a liquid. The amount of water so held, which is completely nonavailable for plants, is very important, for, at least broadly, this amount is indicative of the aggregate of forces which may withhold the water from plants when the amount is larger.

There are, then, several ways in which the availability of soil moisture may be more or less precisely determined. The most precise method is undoubtedly to determine the actual osmotic pressure shown by the soil water when it is present in various amounts or percentages. This of course implies somewhat exhaustive study of each soil whose moisture condition in the field is a matter of interest. In the present study a single approximate determination of osmotic pressure is available for each of only about half the individual soils which are of interest. This determination was made by the vapor-transfer method under conditions far from ideal.

Another method is that of comparing the current moisture percentage for each soil with that percentage which represents the completely nonavailable moisture. This, of course, must have been determined by a wilting test in connection with each soil, or approximately through some such physical measurement as the moisture-equivalent or capillarity determination. As fully explained in "Research Methods in the Study of Forest Environment," the "availability" is expressed by the ratio of the available moisture to the whole. This gives a quantity always less than unity, which has a certain logical value, as—

$$A = \frac{M - WC}{M}$$

in which M represents current moisture and WC the wilting coefficient.

Or, finally, granting that within a single soil type there may be a fairly constant relation between the water-holding properties as determined mechanically and the water-withholding properties in the osmotic sense, the current moisture may be related to the moisture equivalent of each soil, and a purely arbitrary ratio may be obtained for purposes of comparison. This method is almost certain to be misleading if radically different types of soil are involved in the comparison.

Method of securing soil-moisture data.—During 1910 and 1911, when only three forest sites were being studied at the Fremont Experiment Station, the attempt was made to secure samples of the native soil at frequent intervals in the usual manner, namely, by means of a tubular soil borer. These samples were usually taken in triplicate at points near the centers of the respective stations, and, like all other samples considered in this study, were dried in a water-bath oven at the temperature of boiling water, which at the Fremont Forest Experiment Station is approximately 92° C. Until 1915, drying for 8 hours was considered adequate, in view of the small size, coarseness, and mineral character of the samples; but later this period was extended to 24 hours, and the water in the bath was kept boiling for at least the last 5 or 6 hours of the period. No allowance was made for varying vapor pressures, which, being generally low, probably made the drying as complete as though brought about by a higher temperature in a more humid locality.

This plan for sampling the native soil at the several stations was not satisfactory, because, as has been said, the soil of the Pikes Peak region in most situations and except for a few inches at the surface, is disintegrated granite in situ, and is not only very unyielding to penetration but almost entirely lacking in cohesive properties when once loosened. Hence it required, in the first place, great labor to sink the soil borer, and, in the second place, great ingenuity

to withdraw the desired sample. When the soil was very dry the obtaining of samples at a depth of 2 feet was practically impossible, and samples taken at a depth of 18 inches were substituted.

Even a depth of 2 feet does not seem adequate when one has noted the deep penetration of occasional roots in this soil. Therefore, when in 1914 this study was extended to a greater number of stations both near Fremont and in other localities, a plan was adopted which had been in use at Wagon Wheel Gap since 1911, made necessary there by large rock fragments all through the soil. This was the plan of "soil wells."

The preparation of a "soil well" consists in making an excavation from 18 to 24 inches in diameter and 3½ to 4 feet deep, the space being then filled with the same material as has been taken out, with the exception of the rocks or coarse gravel which interfere with soil sampling. As material must be borrowed from some other place to make up for the coarse material sifted out, the resultant soil in the "well" is, of course, very different from that which previously filled the space.

The following objections may legitimately be raised against soil sampling under these conditions:

(1) The "well" soil, weight for weight or volume for volume, will possess a higher water-holding capacity than the native soil, on account of the absence of the rock fragments, which are of relatively little importance in water storage.

(2) The well soil will at the outset be of the same composition from surface to bottom, whereas the native soil may vary greatly with change in depth.

(3) The well soil, not being protected and held by humus accumulations at the surface, will tend, through leaching and transport of fine material, to become coarser at the surface and of finer texture at greater depths; hence the water-holding properties will then vary with depth and in a direction opposite to the variation of the native soil.

(4) Roots are removed in excavating the well, and constant sampling within such a small radius tends to cut off new roots which may penetrate this special soil zone.

Whatever the objections to the method, it is the only method so far found practicable for repeated sampling of rocky, mountain soils. Considerable encouragement may be taken from the assumption, well founded on experimental fact, that when two soils, both moderately moist, are placed in contact, there is a strong tendency for water to move from one to the other until the capillary forces are in equilibrium. If, then, it may be assumed that the moisture equivalents of the native soil and well soil (ME and ME′) represent points at which the two would be in capillary equilibrium, then the probable moisture of the native soil (M) may be computed at any given time, from that determined for the well soil (M′), by the formula—$M=\frac{M' \times ME}{ME'}$.

But also, if it is desired to relate the current moisture of the soil to the moisture equivalent, on the assumption that this ratio expresses in some degree the availability of the water, then it is just as satisfactory to use $\frac{M'}{ME'}$ as $\frac{M}{ME}$, because it has been assumed above that the two are equal.

In considering soil-moisture quantities that approach the wilting coefficient and that present conditions under which capillary movement may almost wholly cease, it is preferable to assume that an osmotic equilibrium is being approached by vapor transfers between the well soil and native soil. In this event, OE, the osmotic equivalent, might be substituted for ME above. Unfortunately, there are neither sufficient osmotic equivalents for well soils and native soils, nor sufficient wilting coefficients for well soils, to make this desirable method of computation possible in the present study.

Comparative moisture of native soils, local stations.—In Table 39 are shown the results of sampling the native soils at three points near the Fremont station, under the conditions already described. These are essentially the data published in the preliminary report on this project (*3*), referring to the three stations which were operated comparatively from March, 1910, to February, 1912.

TABLE 39.—*Comparative moisture data from samples of native soil, July, 1910, to October, 1911.*

Depth.	Station No.	Percentages of dry-soil weight.							Mean annual.[1]	Mean growing season.[2]
		April.	May.	June.	July.	August.	September.	October.		
1 foot	F-1, control	8.75	6.87	5.09	4.98	5.64	4.65	4.40	5.77	5.18
	F-2, pine	7.72	4.96	4.30	5.16	5.78	4.46	3.34	5.10	5.02
	F-3, spruce	.....	16.35	9.92	12.31	9.98	10.07	7.55	11.02	10.67
2 feet	F-1, control	6.01	5.31	2.15	4.28	5.32	5.56	4.15	4.68	4.08
	F-2, pine	4.66	4.19	3.60	4.10	4.34	4.08	3.68	4.09	4.02
	F-3, spruce	.....	8.46	4.99	4.86	9.04	6.68	2.83	6.14	6.34
Average of depths	F-1, control	7.38	6.09	3.62	4.63	5.48	5.10	4.28	5.23	4.63
	F-2, pine	6.19	4.58	3.95	4.63	5.06	4.27	3.51	4.60	4.52
	F-3, spruce	.....	12.40	7.46	8.58	9.51	8.38	5.19	8.58	8.50

[1] Arithmetic means of the months.
[2] Growing-season means obtained by giving September quantities one-third the value of June, July, and August quantities.

It is to be noted that the south-slope pine site (F–2) shows scarcely less moisture than the control station, the latter being subject to no depletion of moisture through use by trees. The spruce site (F–3) at the foot of a north slope shows considerably more moisture than the other stations, except at a depth of 2 feet at the end of the season. This exception would be very significant if the result were based on more data; but, as the measurements covered only October, 1910, they can not be given much weight.

Periodic moisture at the control station.—As the data for native soils are meager and can be compared only on their face value, in the absence of physical data on the soils themselves, an examination may be made of the more extensive data secured by taking samples from the "wells."

In Table 40 are given the monthly mean moisture figures for the control station for the greater part of five seasons. Each mean figure is based on four or five determinations, at intervals of a week, except where otherwise indicated by a number in parentheses, which denotes the number of determinations. Only the data for 1914, 1915, and 1917 are used in computing the averages, as this is the basis at other local stations.

TABLE 40.—*Mean soil moisture at control station as shown by samples from "well."*

Year.	Depth.	Percentages of dry-soil weight.										Mean annual.[1]	Mean growing season.[2]
		Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.		
	Feet.												
1914	1	.....	.....	.....	.....	9.13	8.77	6.84	7.34	7.16	4.82	7.85	8.65
	2	.....	.....	.....	.....	8.71	9.40	7.62	8.38	9.15	7.01	8.65	8.85
	3	.....	.....	.....	.....	8.38	9.82	8.94	8.56	10.00	8.16	9.14	9.08
1915	1	.....	(3) 9.01	8.10	7.50	6.84	8.78	7.91	8.00	7.04	.....	7.90	7.73
	2	.....	10.78	8.84	8.31	8.42	9.14	8.72	8.68	8.31	.....	8.90	8.63
	3	.....	11.29	10.11	10.67	9.41	9.80	9.86	9.28	8.16	.....	9.82	9.95
1916	1	(1) 4.24	7.88	7.34	6.68	8.08	8.82	6.34	6.33	.....	.....	7.35	7.71
	2	6.19	8.14	9.10	7.14	7.52	9.10	7.65	7.32	.....	.....	7.99	7.89
	3	6.06	9.84	10.06	8.50	8.48	10.09	8.32	8.55	.....	.....	9.12	8.95
	S.	.....	(3)	9.49	6.05	5.48	5.78	5.29	2.78	3.61	.....	5.50	5.72
1917	1	.....	7.96	8.48	7.24	6.14	6.81	7.21	6.09	5.91	.....	6.98	6.78
	2	.....	8.78	8.75	8.05	7.05	6.69	7.54	6.87	6.44	.....	7.52	7.29
	3	.....	9.38	9.75	9.82	7.93	7.24	7.39	7.15	7.42	.....	8.26	8.24
1918	S.	.....	.....	(2) 5.54	(3) 4.22	(1) 4.26	(1) 4.07	.....	.....	.....	.....	4.52	4.18
	1	.....	.....	7.40	8.18	6.94	7.62	.....	.....	.....	.....	7.54	7.58
	2	.....	.....	8.16	9.00	7.83	8.15	.....	.....	.....	.....	8.28	8.33
	3	.....	.....	9.35	9.77	9.14	9.14	.....	.....	.....	.....	9.35	9.35
Averages 1914–1915.	S.	.....	.....	9.49	6.05	5.48	5.78	5.29	2.78	3.61	.....	5.50	5.72
	1	.....	8.48	8.29	7.37	7.37	8.12	7.32	7.14	6.70	.....	7.60	7.59
	2	.....	9.78	8.80	8.18	8.06	8.41	7.96	7.98	7.97	.....	8.39	8.19
1917.	3	.....	10.34	9.93	10.24	8.57	8.95	8.73	8.33	8.53	.....	9.20	9.20

[1] Omit December, 1914, and March, 1916, in computing yearly averages.
[2] The values for June, July, and August are added to one-third of the September value and the sum divided by 10/3.

(1) The moisture at 1, 2, or 3 feet is remarkably uniform in different years if the growing-season means be considered. This may be due in part to the lack of tree growth near the "well" and the inability of grasses and herbs to reach the deeper moisture.

(2) The moisture is less during July and late summer than in the spring and early summer, but is well maintained by precipitation after July.

(3) The year 1917 was the driest of record, the precipitation and especially that for the growing season being below normal.

(4) The mean figures for the soil well, for depths of 1 and 2 feet, when reduced to terms of native soil by use of the moisture-equivalent ratios, are of lower value than the actual figures for native soil obtained during 1910–11. As the early sampling of the native soil covered a considerable area, and as the soil is by no means uniform over large areas, the lack of correlation may mean nothing more than a difference in the conditions surrounding the measurements during the two phases of the study.

Comparative moisture in wells, all types.—In Table 41 is given a summary of the well-moisture data for all stations in the study where data have been obtained. For all local stations except F–12, F–14, and F–15, the data are for 1914, 1915, and 1917, beginning with July, 1914. For Monument the period is 1915 to 1918, inclusive. For Foxpark it is August, 1916, to August, 1918. For Wagon Wheel Gap it is (A1 and A2), August, 1913, to August, 1918; (D) August, 1913, to October, 1917; and (F) July, 1915, to October, 1917. As the unusually dry year 1917 is included in each average, it is not thought the variations in period will introduce any serious discrepancy.

TABLE 41.—*Mean soil moisture in "wells."*

Station No.	Type.	Depth.	Percentages of dry-soil weight.									Mean annual.	Mean growing season.[1]
			Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.		
		Feet.											
		S.	.....	.....	9.49	6.05	5.48	5.78	5.29	2.78	3.61	5.50	5.72
F-1	Control	1	.....	8.48	8.29	7.37	7.37	8.12	7.22	7.14	6.70	7.60	7.59
		2	.....	9.78	8.80	8.18	8.06	8.41	7.96	7.98	7.97	8.39	8.19
		3	.....	10.34	9.93	10.24	8.57	8.95	8.73	8.33	8.53	9.20	9.20
		S.	.....	.....	7.64	2.52	5.44	4.54	5.11	3.57	2.42	4.46	4.26
F-2	South-slope yellow pine	1	.....	11.84	10.29	8.50	8.62	9.90	8.56	8.19	7.95	9.23	8.96
		2	.....	12.93	10.86	10.05	10.97	10.30	9.94	9.73	9.56	10.54	10.39
		3	.....	14.98	12.79	12.59	11.70	10.47	10.51	10.28	11.15	11.81	11.48
		S.	0.64	12.92	8.89	4.35	3.03	5.72	5.82	7.74	6.84	6.22	4.51
M-1	Monument yellow pine	1	7.21	10.30	10.57	8.90	5.91	5.96	4.96	7.04	6.10	7.44	6.73
		2	9.42	10.85	11.99	10.82	7.55	6.00	5.03	6.75	6.94	8.37	7.81
		3	14.10	12.20	12.48	11.96	9.98	7.86	5.90	9.06	8.74	10.25	9.53
		S.	.....	.....	9.33	4.18	5.38	5.82	6.52	3.64	4.74	5.66	5.27
F-4	Yellow pine-fir	1	.....	.....	10.08	8.75	8.47	9.11	7.72	6.53	7.52	8.31	8.07
		2	.....	.....	11.70	10.75	10.60	10.86	10.57	8.92	9.49	10.41	10.72
		3	.....	.....	12.65	12.64	10.62	11.31	10.64	10.60	10.86	11.33	11.44
		S.	.....	.....	10.80	5.13	6.64	6.81	8.93	4.91	8.76	7.43	6.47
F-12	Ridge yellow pine	1	.....	.....	11.44	10.62	9.76	11.38	11.04	11.66	10.28	10.88	10.63
		2	.....	.....	12.97	12.22	10.96	11.64	12.00	12.11	12.38	12.04	11.65
		3	.....	.....	13.26	12.42	11.41	12.21	13.14	13.10	13.23	12.68	12.13
		1	.....	.....	14.67	11.34	9.92	11.40	9.54	12.68	.....	11.59	10.75
W-A2	South slope Douglas fir	2	.....	.....	17.60	12.68	12.38	11.73	10.88	12.36	.....	12.94	12.12
		3	.....	.....	16.43	14.42	14.30	12.65	11.12	13.04	.....	13.66	13.52
		S.	.....	.....	24.02	10.64	9.62	11.97	8.56	4.39	6.76	10.85	10.53
F-9	Fir, north, uncut	1	.....	.....	18.89	13.52	12.23	14.01	12.92	11.50	12.66	13.68	13.22
		2	.....	.....	19.26	16.61	13.89	15.02	14.33	13.66	13.28	15.15	15.09
		3	.....	.....	17.34	17.91	13.66	14.38	14.62	13.62	12.42	14.85	15.25
		S.	.....	.....	13.18	6.13	11.81	10.50	11.06	7.16	3.90	9.11	9.64
F-14	Fir, north, half cut	1	.....	.....	14.54	12.82	12.94	13.94	13.32	12.10	9.93	12.80	13.24
		2	.....	.....	15.15	12.70	13.68	14.59	14.40	14.25	12.61	13.91	13.73
		3	.....	.....	17.83	13.56	14.36	15.21	14.89	14.61	14.49	14.99	14.43
		S.	.....	21.72	11.77	6.64	9.24	9.89	10.51	6.86	4.66	8.51	8.78
F-15	do	1	.....	.....	13.80	12.85	12.18	14.64	13.30	11.41	9.06	12.46	13.23
		2	.....	.....	14.62	13.57	12.86	14.84	14.20	13.12	12.40	13.66	13.80
		3	.....	.....	16.56	14.25	14.24	15.50	14.52	13.88	14.15	14.73	14.65
		S.	.....	16.10	14.27	9.33	5.93	8.76	8.61	6.21	8.21	8.76	8.06
F-8	Fir, north, clear cut	1	.....	.....	14.44	12.69	10.81	12.28	12.13	11.50	12.26	12.44	11.95
		2	.....	.....	13.48	14.66	13.38	12.58	13.13	12.89	13.74	14.12	15.00
		3	.....	.....	16.84	15.47	13.18	13.16	13.70	13.73	14.47	14.36	13.91
		S.	.....	.....	12.02	5.94	5.26	6.22	6.98	5.27	5.03	6.67	5.92
F-7	do	1	.....	.....	13.60	12.31	11.30	11.87	11.57	11.78	10.91	11.91	11.80
		2	.....	.....	14.61	13.34	11.59	12.34	12.15	12.65	12.65	12.76	12.40
		3	.....	.....	14.82	13.01	11.00	11.99	11.79	12.36	11.97	12.42	11.98
		S.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
W-A1	North slope Douglas fir	1	.....	.....	23.60	20.48	18.46	18.58	18.62	18.80	.....	19.76	19.12
		2	.....	.....	25.60	22.24	20.98	20.58	21.66	20.66	.....	21.95	21.31
		3	.....	.....	24.63	25.10	25.10	25.92	24.46	23.52	.....	24.79	25.28
		S.	.....	.....	.....	14.84	7.38	5.29	5.86	5.16	11.51	8.34	8.84
F-11	Lodgepole, Wyoming	1	.....	.....	.....	15.30	9.62	7.93	6.75	6.67	6.33	8.77	10.53
		2	.....	.....	.....	16.55	13.00	9.91	7.05	7.36	7.28	10.19	12.54
		3	.....	.....	.....	17.16	17.66	13.00	8.16	9.44	10.51	12.66	15.16
		S.	.....	.....	16.43	10.53	7.89	10.31	13.16	5.81	3.85	9.67	9.85
F-3	Canyon spruce	1	.....	.....	15.88	12.15	11.57	12.19	10.88	10.78	10.69	12.02	11.88
		2	.....	.....	15.90	12.44	12.46	12.68	12.06	11.48	11.61	12.66	12.48
		3	.....	.....	13.43	13.84	12.88	13.23	12.86	12.91	12.73	13.13	13.27
		S.	.....	.....	23.82	12.29	7.51	11.69	10.72	4.12	3.82	10.57	10.52
F-5	do	1	.....	.....	14.34	13.44	12.86	13.50	11.94	11.77	11.36	12.74	13.13
		2	.....	.....	14.74	14.28	14.12	14.42	12.28	12.73	12.83	13.63	14.07
		3	.....	.....	15.89	17.90	17.59	16.49	16.86	16.11	15.69	16.65	17.23
W-D	High spruce, burn	1	.....	.....	30.20	24.08	22.42	23.38	23.58	23.24	.....	24.48	23.32
		2	.....	.....	35.20	28.28	25.00	26.92	27.54	25.40	.....	28.06	26.81
		3	.....	.....	27.80	28.20	23.62	24.64	24.84	23.48	.....	25.43	25.42
		1	.....	.....	.....	27.90	22.30	20.77	20.23	19.63	.....	22.17	23.31
W-F	High spruce, forest	2	.....	.....	.....	32.20	27.37	21.40	20.50	20.73	.....	24.44	26.34
		3	.....	.....	.....	42.30	28.17	22.00	20.37	20.60	.....	26.69	29.78
		S.	.....	.....	12.08	7.35	7.88	9.47	11.46	3.84	3.29	7.91	8.56
F-6	West slope limber pine	1	.....	.....	15.24	11.52	10.76	13.00	12.13	10.65	10.62	11.99	11.80
		2	.....	.....	15.78	12.42	11.51	12.82	11.74	11.68	11.65	12.51	12.20
		3	.....	.....	15.39	13.09	12.21	13.71	13.20	13.32	13.05	13.42	13.02

[1] Growing-season means obtained by giving September quantities one-third the value of June, July, and August quantities.

Surface moisture in the wells was measured for local stations only in 1917, and at Wagon Wheel Gap not at all.

As the large mass of figures in Table 41 is difficult to grasp, the averages by species groups are presented in Table 42.

TABLE 42.—*Average "well" moisture for growing season.*

Group.	Depth.			
	Surface.[1]	1 foot.	2 feet.	3 feet.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Control station	5.72	7.59	8.19	9.20
Four western yellow pine sites	5.13	8.75	10.14	11.14
Seven Douglas fir sites	8.59	13.33	14.78	15.57
Four spruce sites	10.18	17.90	19.92	21.44
One lodgepole pine site	8.84	10.53	12.54	15.16
One limber pine site	8.56	11.80	12.20	13.02

[1] Local stations only and season of 1917 only.

On the face of these data it is very evident that the yellow pine sites possess less moisture during the growing season than do the Douglas fir sites, which, with one exception, are northerly aspects—and likewise that the spruce soils have a still larger supply. It is unsafe to estimate the positions of the limber pine and lodgepole pine sites without some correction for the type of soil involved, as there is here no opportunity for compensating peculiarities.

In considering the high average values for the spruce sites, however, it is worth while to mention that the group of four was made up of two local stations and also of two at Wagon Wheel Gap whose soils have much better water-holding properties. Thus, for example, the mean 1-foot moisture for the local sites is only 12.5 per cent, or almost the same as for the local Douglas fit sites, but the corresponding figure for the heavier Wagon Wheel Gap soils is 23.32 per cent. It will be shown later, when wilting coefficients are considered, that this apparent difference is unreal, so far as availability of the water is concerned.

In the yellow pine group, the relatively high moisture contents at Stations F–4 and F–12 are worthy of note, as both of these sites are fairly favorable for Douglas fir. Of the two, Station F–12 has the more favorable conditions if allowance is made for the quality of the soil.

As data are available for every site for the season of 1917, which has previously been mentioned as the driest year in which extensive records have been made, it is desirable to give consideration to minimum moisture conditions, which are far more likely to give something significant with respect to the survival of the species. In using the 1917 data, the individual and successive moisture determinations are found to be so variable that it seems unsafe to base any conclusions on single observations. The most meager basis would appear to be the average for a month, made up from four or five weekly determinations. The lowest monthly average for each station and depth has, therefore, been accepted. In Table 43 the results are grouped according to the plan of Table 42.

TABLE 43.—*Minimum (month) "well" moisture during season of 1917 and percentage ratio to mean growing-season moisture (in parentheses).*

Group.	Depth.			
	Surface.	1 foot.	2 feet.	3 feet.
Control station	(49) 2.78	(78) 5.91	(79) 6.44	(78) 7.15
Four yellow pine sites	(66) 3.37	(65) 5.72	(63) 6.40	(65) 7.28
Seven Douglas fir sites	(66) 5.67	(76) 10.18	(75) 11.08	(79) 12.31
Four spruce sites	(38) 3.84	(71) 12.66	(73) 14.53	(73) 15.66
One lodgepole pine site	(35) 3.08	(68) 6.66	(62) 7.72	(53) 8.11
One limber pine site	(38) 3.29	(72) 8.46	(78) 9.49	(83) 10.87

The data in Table 43 do not appear essentially unlike those of Table 42 in fixing the relative positions of the species, yet the parenthetical figures showing the relation between these minima and the approximately normal growing-season condition are full of significance. It is to be noted that the degree of exhaustion as indicated by these percentages is nearly the same for the 1, 2, and 3 foot depths with perhaps a slight tendency toward greater exhaustion at a depth of 2 feet than elsewhere. On the other hand, although the yellow pine sites do not show greater exhaustion at the surface than in the deeper soil and the north-slope fir sites show only slightly greater drying of the surface, the spruce sites, as well as the limber pine and lodgepole pine sites, show very marked drying out. In the spruce sites this can not be ascribed to insolation; it must be charged in part to the loose duff which forms the surface layer and in part to the prevalence of roots near the surface. As the soil wells can not possibly show either of these factors fully, it is evident that the natural surface soil in a dense spruce forest must represent a very great degree of drought. That is, perhaps, the most striking point that has been brought out by all of the soil-moisture determinations, especially when one considers the importance already attached to surface temperatures. Calculations as to the availability of the moisture, made on the basis of moisture equivalents, indicate that one of the two spruce sites for which the surface data are available becomes physiologically drier than any of the others, and the second is drier than any except the warmest yellow pine sites and the wind-exposed limber pine site.

The attempt to reduce the data of Table 42, first, to terms of moisture percentages for the native soil and then to terms of availability, does not materially alter the evidence of Tables 42 and 43, namely, that the yellow pine sites are the most arid and that the spruce situations are only slightly moister than the north slopes which bear Douglas fir. On the other hand, these calculations do show that, owing to a very sandy soil used in the soil well, the lodgepole site is considerably more favorable than the original moisture data would indicate. The approaches, through osmotic equivalents, through the direct ratio of moisture contents to moisture equivalents or through consideration of the wilting coefficients, all produce, as

between the forest types, essentially the same relations. All tend to show that the differences between sites in availability of the moisture are less than are indicated by the bare moisture contents.

Rather for the purpose of illustration than because of the value of the data, calculations of the probable natural soil moisture and of the availability of this moisture are presented in Table 44. These calculations can not be extended to the surface-moisture values, because the native surface soils have not been physically examined. Moreover, such calculations would be of little value, because the surface soils of the wells are so directly influenced by atmospheric conditions.

Probably the most valuable feature of Table 44 is the clear way in which it shows that the high moisture percentages obtained with the heavy soil at Station D, Wagon Wheel Gap, are really on a level with those for the local spruce stations. The slightly higher availability at Station D is easily explained by the almost complete absence of forest. Similarly, although the calculations can not be carried out for the two Douglas fir stations, the high wilting coefficients indicate that Station W–A1 (north exposure) must be just about on a par with similar local stations, but that the strongly exposed Station W–A2 is certainly much more arid.

As has been pointed out, these calculations show the lodgepole pine site to be very moist. This may be due in part to the fact that only a few trees surrounded the soil well, but is probably the result of low evaporation stresses. The limber-pine site is seen to be in a class with the average yellow-pine site. Among the local stations subject to practically the same atmospheric conditions it is evident that direct insolation tends to keep the more insolated pine sites in a drier state than the others; but the very slight difference between fir slopes and spruce bottoms after a prolonged period of drying indicates that each soil, through direct drying and the drying accomplished by the trees, tends to come into vapor-pressure equilibrium with the atmosphere. The probabilities are, therefore, that in the event of more prolonged drought, sufficient to permit an equilibrium to be reached, equally insolated soils will attain the same status quite regardless of the character and amount of vegetation thereon. This is of the utmost importance, indicating, in the present case, that the moisture supply is effective only in controlling the number of individuals and can not differentiate between species, at least as between spruce and fir sites.

It is fairly evident, then, that soil moisture below the surface layer is only an incidental factor in the distribution of the several species. Strongly insolated sites and those exposed to the higher temperatures and to the greater atmospheric stresses of low elevations, as might be expected, are always the driest, but their most important feature, owing to the close connection between insolation, surface temperatures, and surface moisture, is doubtless the very rapid drying of the surface layer after every rain, rather than any decided lack of moisture at greater depths.

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TABLE 44.—*Calculated minimum moisture in soils during 1917 and relative availability.*

Station No.	Type.	Depth.	"Well" moisture, lowest month (M').	Ratio ME/ME'.	Calculated moisture of native soil (M).	Nonavailable moisture by test (WC).	Availability $\frac{M-WC}{M}$
		Feet.	*Per cent.*		*Per cent.*	*Per cent.*	
M-1	Western yellow pine	1	3.59	0.853	3.06	2.36	0.229
		2	3.90	.632	2.46	1.53	.378
		3	3.47	.647	2.25	1.68	.253
F-2	do	1	4.93	.582	2.87	1.16	.596
		2	5.96	.636	3.79	2.63	.306
		3	6.89	.631	4.35	2.67	.386
F-12	do	1	9.35	.630	5.89	1.99	.662
		2	10.14	.600	6.08		
		3	11.16	.495	5.52	1.97	.643
F-4	do	1	5.02	.526	2.64	1.79	.322
		2	5.61	.475	2.66	1.28	.519
		3	7.61	.375	2.85	1.43	.498
Average	do	1	5.72				.452
		2	6.40				.401
		3	7.28				.445
F-7	Douglas fir	1	9.03	.463	4.18	1.26	.699
		2	10.02	.478	4.79	1.85	.614
		3	10.09	.486	4.90	1.24	.747
F-8	do	1	7.38	.387	2.86	1.76	.385
		2	9.99	.325	3.25	1.64	.495
		3	10.80	.263	2.84	1.18	.585
F-14	do	1	12.38	.481	5.96	1.79	.700
		2	12.42	.536	6.66	2.06	.691
		3	13.23	.371	4.91		
F-15	do	1	10.81	.483	5.22	2.26	.569
		2	11.77	.589	6.93		
		3	13.13	.622	8.17		
F-9	do	1	7.46	.393	2.93	1.62	.447
		2	9.67	.393	3.80	.96	.747
		3	9.69	.435	4.22	1.62	.616
W-A1	do	1	16.20			5.76	
		2	16.20				
		3	20.60			6.63	
W-A2	do	1	8.00			5.04	
		2	7.50				
		3	8.60			5.70	
Average	do	1	10.18				.560
		2	11.08				.638
		3	12.31				.649
F-3	Engelmann spruce	1	6.68	.645	4.31	1.54	.643
		2	9.40	.535	5.08	1.51	.700
		3	11.16	.327	3.65	1.45	.603
F-5	do	1	7.57	.408	3.09	2.12	.314
		2	10.03	.462	4.63	2.64	.430
		3	11.56	.405	4.68	1.98	.577
W-D	do	1	17.50	1.033	18.08	7.56	.582
		2	19.00	.876	16.64	3.59	.784
		3	20.60	.893	18.40	4.14	.775
W-F	do	1	18.90				
		2	19.70				
		3	19.30				
Average	do	1	12.66				.516
		2	14.53				.638
		3	15.66				.652
F-11	Lodgepole pine	1	6.66	2.017	13.43	4.72	.649
		2	7.72	2.437	18.81	3.65	.806
		3	8.11	1.743	14.14	2.99	.789
F-6	Limber pine	1	8.46	.494	4.18	2.44	.416
		2	9.49	.385	3.65	2.63	.274
		3	10.87	.329	3.58	1.85	.483
F-1	Control station	1	5.91	.520	3.07	2.31	.248
		2	6.44	.436	2.81	.93	.669
		3	7.15	.526	3.76	.76	.798

At the other extreme stand the canyon and lower-slope spruce sites, whose soil is mainly transported. This soil is of finer quality than that of the slopes, is rich in humus, which may blow into the low places as well as wash in, and consequently is of the greatest water-holding capacity. This great capacity and the usually high level of the moisture content encourage dense stands. Only spruce can grow in the densest stands; other species are excluded not by lack of moisture, or by too much moisture, but by lack of insolation. It seems possible that these very sites may, after unusually prolonged drought, prove to be the driest. The difficulty which is often experienced in starting plantations in gulches which encourage heavy vegetation is testimony to the extreme desiccation of such soils when rain is withheld. In 1909, the writer definitely found the bottom situations to be the driest of all the sites in late summer in the Nebraska sand hills.

The Douglas fir sites on north slopes are almost as moist as the lower spruce sites, and probably do not dry out to so great a degree. The surface conditions, especially, remain fairly favorable because of the lack of drying insolation. On the other hand, the evidence of the south-slope fir site at Wagon Wheel Gap, and the occurrence of fir seedlings almost on the roots of yellow pine on south slopes, shows convincingly that the need of this species is not for great moisture, but rather for moderate temperature conditions.

RECAPITULATION.

GENERAL CHARACTER OF THE CLIMATE.

The mountain climatic conditions, which have been portrayed mainly through the relatively long-term records at the Fremont Forest Experiment Station, at an elevation of 8,836 feet on the eastern slope of Pikes Peak, may be characterized as follows, in terms which apply generally to the forest types (fig. 10).

(1) The summer or growing-season conditions are not unfavorable to the growth of vegetation that has very moderate heat requirements. The mean growing-season temperature is about 55°, with the period from June 10 to September 10 free from freezing temperatures. Almost 50 per cent of the total precipitation occurs during the growing season (June 1 to September 10, as here considered) following a brief drought in May or early June; hence the moisture of the deeper soil stands throughout the season at a favorable point, rarely if ever approaching the nonavailable content. This period is never characterized by high winds, and great atmospheric dryness occurs only when the drought period extends well into June.

(2) With the cessation of daily showers, which rapidly decrease in number and volume after August 15, a period of clear, dry weather occurs which rapidly depletes the moisture of the surface soil and which may, by the end of October, cause the death of a large proportion of the new seedlings of the season, most of which will not have germinated before July, and will therefore be very immature and poorly rooted. In this wholesale elimination, which doubtless makes some distinction between species, the early frosts may have some influence, but do not appear to be so important as drought.

(3) The winter temperatures at middle and lower elevations in the Pikes Peak region are rarely very low; relatively warm, strong winds occur frequently from January to March; and evaporation stresses are very telling, except at high elevations where the air temperature rarely goes higher than 32° F. The precipitation also during the winter months is very low. Clear weather and the lack of material for evaporation result in great dryness of the atmosphere. Another effect of the lack of snow is seen in the early and deep freezing of the soil, except on well-insolated exposures. In the main, then, trees are subjected to conditions which induce rapid transpiration, and at the same time are cut off from their moisture supply by the freezing of the moisture in the soil. Obviously, these conditions are not a less severe strain upon the well-established tree than

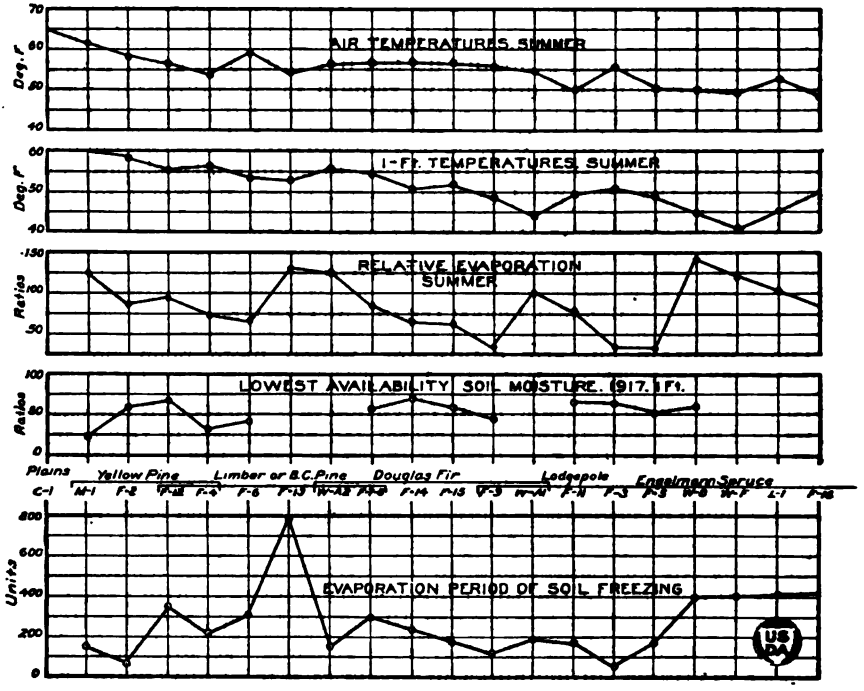

FIG. 10.—Summary of the several conditions in the various forest types.

upon the seedling which may secure protection through shading or through a temporary snow blanket.

It is believed that these winter conditions, rather than the poor quality of the soil, delimit the growth of all forest trees in the locality, and produce a scrubby stand which on some sites has apparently reached its limit at a height of 40 feet or less.

(4) The extension of observations to other localities both north and south of the Pikes Peak region indicates a less complete development of most of the unfavorable features of climate. To the south, to be sure, the spring drought is more pronounced and may possibly destroy seedlings of the preceding season. The summer rainfall is no more abundant, but the fall drought is of less duration; a snow

cover is secured earlier; and the low winter air temperatures are much less conducive to evaporation. To the north, in the lodgepole pine type, precipitation is insufficient to balance losses from May to August, and a pronounced drought develops toward the end of summer. However, as early snows are heavy, there is no acute problem of soil moisture, nor are there menacing evaporation stresses in winter. No doubt the evaporation problem is present at low elevations in Wyoming, South Dakota, and Montana; but in the Black Hills, where yellow pine develops excellently both as to reproduction and growth rate, it is safe to say that both soil and atmospheric dryness are considerably modified by an abundance of snow and by low air temperatures.

TEMPERATURES AND TEMPERATURE GRADIENTS.

The study in the Pikes Peak region has shown that a fairly regular change in air temperatures occurs with change in elevation, amounting to 2.8° F. per 1,000 feet for the year as a whole, 2.9° for the growing season, and 3.3° at its maximum in April. This applies to what may be called "neutral" sites at all elevations except the highest one. Early study showed the air temperatures 20 feet above the ground to be not essentially different for opposing slopes at the same elevation; but near the ground southerly exposures have been shown to be warmer than the mean for the elevation, and northerly exposures cooler, to an extent compatible with the types which they respectively encourage. These contrasts are more clearly seen in the soil temperatures.

The Wagon Wheel Gap locality in southern Colorado shows a temperature gradient of about 2.3° F. per 1,000 feet for the growing season. During the winter months this temperature gradient is not infrequently inverted, and in exceptionally cold weather there may be an inverted gradient of 4° per 1,000 feet, the lowest station here being in a valley affected by cold-air drainage. At a middle elevation this locality is always colder than the Pikes Peak region.

The relation of soil temperatures to air temperatures is by no means constant for the different forest types. During the growing season such differences as exist between air and soil temperatures are largely the results of local insolation, which does not affect local air temperatures so markedly as it does the temperature of the ground near its surface. If the year is taken as a whole, soil temperatures may not reflect the air temperatures of different localities, because of the marked influence on the former of a light or heavy snow blanket.

Because summer soil temperatures agree more closely with the type differences produced by different exposures, no less important than those produced by differences in elevation; because soil temperatures may be seen to have a more direct influence on type compostition at the time of initiation of seedlings; and because winter soil temperatures appear to be indirectly related to survival, through soil moisture, as fully as are air temperatures through evaporation, the detailed consideration of soil temperatures has proved more valuable in the present study than the consideration of air temperatures, even though surface temperatures of the soil, which should by all means be recorded, are largely lacking.

Response of the species to temperatures.—There is every reason to believe that insolation exercises a direct control over the distribution of the species; but in the total absence of direct measurements of insolation, temperature data must be relied on to carry out this idea. It is, of course, difficult to distinguish between the direct effects of insolation and such indirect effects as soil drying; but the total evidence points to the direct and the temperature effects as influencing most strongly the selection of the species for each site, except possibly with spruce, which is more susceptible to drying than to heat injury.

The range of either air or soil temperatures measured in any one type of forest is, however, so small as to indicate that temperatures during the growing season can not vary widely without causing the elimination of the given species, or at least its domination by some other species. It is true that on the lower margin of the mountain forest yellow pine seems to thrive under a wide range of temperatures in different localities. This apparently greater adapatability of yellow pine may be due partly to the fact that, wherever it may extend downward into warmer zones it finds no important competitors, and therefore may exist even if its rate of growth becomes negligible. More important, however, is the consideration that air or soil temperatures as recorded probably mean almost nothing. The temperatures which the young plant experiences will be most intimately bound up with the temperature of the surface of the soil. As may be readily proven, relative to other temperatures the surface maxima, which are probably most important, will vary widely according to the amount of rain and the moistness of the soil during the critical summer months.

A mean growing-season soil temperature of about 58° to 62° F., at a depth of 1 foot, permits the establishment of western yellow pine. At 55° or 56° Douglas fir will appear with the pine. At 52° or 53° fir will probably predominate, but there may still be some reproduction of yellow, limber, or bristlecone pines, the species depending apparently on winter evaporation stresses. At 50° we may expect almost pure Douglas fir if moisture is favorable. At 44° to 48° and perhaps higher, Engelmann spruce reproduction will come in under fir and doubtless ultimately replace it. Spruce may hold complete sway where the soil temperatures are from 40° to 50°, but probably does not reproduce at all where this lowest temperature prevails; the stand must be thinned out before it is rejuvenated.

Lodgepole pine, probably has temperature requirements, for satisfactory reproduction, between those of yellow pine and fir. The single site studied shows soil temperatures a little lower than those for fir, and air temperatures no higher than for good spruce sites. However, the well-known proclivity of lodgepole reproduction for denuded sites, where the radiation is intense, and some few measurements on such sites not conducted long enough to establish averages, show the reason for the usual failure of lodgepole to reproduce under its own canopy and indicate the higher heat requirement of this species. Measurements by Notestein [11] at midsummer in 1912 showed the soil temperatures at 6 inches to be at least 4° higher in an area from which the pine had been cut and the brush burned than in the virgin forest. In each place measurements were taken at about 12 points.

[11] Notestein, F. B., forest examiner, Forest Service, "Progress Report, Exp. R—11," 1923.

Limber pine sites even at high elevations show summer temperatures higher than those for Douglas fir, and undoubtedly reaching almost as great extremes as yellow pine soils.

It is not necessary for a proper explanation of the selective process of insolation to assume, as the present writer once did (*4*) that the temperature of the environment appreciably influences the chemical effectiveness of sunlight; but it is necessary to recognize that a high temperature may contribute to the superheating of the plant tissues, and that a dry atmosphere and wind decrease the liability by facilitating the cooling process of evaporation.

The idea that protection arises from the cooling caused by transpiration is by no means new. In 1902, Barnes (*2*) wrote:

> 34. Under the present organization of plants exposure of wet cell walls to the atmosphere is indispensable for the solution of necessary gases, oxygen and carbon dioxide, the plant being debarred from waterproofing the cell wall so long as gas absorption is necessary. Transpiration is, therefore, considered as unavoidable, though in itself a constant menace to life and activity. Advantage has doubtless been taken of the xylem bundles to facilitate the movement of solutes, but there is no reason to think this essential. Transpiration also has become a protective factor with sun plants, whose temperature is thereby kept within reasonable bounds. (Since reading the paper the author has ascertained that in certain points his view of transpiration coincides with those expressed by Dr. C. E. Bessey in a paper on the function of stomata, published in Science N. S. 7:13–16, 1898.)

Each species may have, then, functional limits expressed in a minimum amount of light and a certain maximum temperature. It is evident also that the several species may exhibit differences not only in "shade tolerance" but in light tolerance as well, which will be especially marked when the seedling is very young and is subjected to the reflected light from the ground surface and to the attendant temperatures which may prevail there. This limited light tolerance is probably due to the direct effect of heat upon protoplasm. The experiments reported have not, it is true, shown the species to be sensitive to excessive heat in proportion to their shade tolerance. Apparently Engelmann spruce is adapted to a much wider range of light conditions than the other species, while Douglas fir is most clearly sensitive to the heating effects of strong light, and with both spruce and lodgepole pine, the injury to young seedlings evidently arises from loss of water rather than, or commonly earlier than, from superheating.

WIND, HUMIDITY, AND EVAPORATION.

Wind velocities vary widely in different situations and localities of the mountains, recorded velocities depending largely on the immediate conditions of exposure. In general, wind velocities are much higher in winter than in summer, and much higher at high elevations than at low, exposures being equal, because of the fact that the higher atmosphere is more turbulent. Beyond this, comparisons of the sites studied are unsafe. It is entirely in agreement with the physiological qualities of the species to find spruce tolerating much greater exposure to wind, than does yellow pine.

Humidity, as measured by saturation deficits, varies more widely locally, on account of differences in air temperature and not so much by reason of changes in vapor pressure. A wind in descending the slope of Pikes Peak may actually gain some moisture, but its temperature increases so much more rapidly that it gains very quickly in saturation deficit and evaporating power.

These computations show a maximum evaporation of about 100 units in the thrifty yellow pine forest, during the mean period of frozen soil. Yellow pine barely exists, in mixture with limber pine and Douglas fir, where the evaporation may be 350 units. Nearly 300 units are possible in an opening of the north-slope Douglas fir forest, but within the forest the total stresses are less than one-third as great. The same type at Wagon Wheel Gap shows the possibility of about 300 units, but only half as much on a well-insolated south slope. The spruce sites show from 60 units (low canyon type) to 400 units at timberline. The greatest loss noted occurs on a high, windswept ridge, where limber pine is now the only claimant of the ground. The lodgepole pine type in southern Wyoming, although soil temperatures are slightly below freezing for five months, has evaporation stresses barely exceeding those of the yellow pine type. Possibly the rapidly increasing exposure to wind at high elevations and the increasing length of the period of soil freezing would set a limit to the upward extension of spruce, though the limit of ability to resist the mechanical effect of wind and snow may be reached first. Regarding drought in alpine situations and the degree of xerophytism which it develops, the following citation from Cowles (*11*) is of interest:

> The distribution of alpine plants, however, is apparently due in large degree to edaphic conditions. The timberline in general may probably be referred to atmospheric conditions, but the marked gaps and oscillations which usually occur are due in a large measure to soil relations. While xerophytes increase in the alpine parts of mountains, it is to be observed that edaphic as well as climatic factors become more xerophytic upwards. While changes occur as one traces one type of edaphic formation upwards, these changes are far less marked than are those observed in passing from one edaphic formation to another.

Although soil freezing does not appear to be a generally critical factor in relegating the species of the central Rocky Mountains to their respective sites, it would seem to have a marked influence on the distribution of yellow pine in view of the sensitiveness of the species to winter drying. "Winter killing" rarely does more than defoliate the established tree, and a few trees of this species have become established where the exposure must be very severe. However, the heavy loss of seedlings of yellow pine during the winter, in both plantations and natural stands, suggests that on sites which do not hold a snow blanket the fatal effects are most likely to be felt by very young trees, both because there is less opportunity for storage of moisture in the tree itself, and on account of the nearness of the foliage to a reflecting surface which would greatly augment transpiration.

PRECIPITATION AND SOIL MOISTURE.

The annual precipitation at the control station is about 22 inches, of which nearly one-half occurs during the growing season. In the Pikes Peak region this annual amount decreases to 14 inches at the base of the mountains, and increases to nearly 25 inches in the spruce zone. There is, then, an increase of about 2.4 inches per 1,000 feet increase in elevation. In the Rio Grande region the precipitation seems to be somewhat less at a middle elevation, but is fully as much at high elevations. In southern Wyoming the lodgepole pine type, slightly higher than the control station, has only 15.5 annually, and only one-fourth of this amount occurs during the growing season.

Precipitation measurements are obviously unsatisfactory for the close analysis of contiguous forest types, since these may receive equal amounts and yet be radically at variance in their moisture conditions. With the precipitation known, measurements of evaporation near the ground should give a very good idea of the extent to which the moisture supply is dissipated, or conserved for the uses of vegetation. It has been shown that the higher forest types have somewhat less evaporation than those at low elevations, for the year as a whole, and that northerly exposures are much less rapidly dried out by insolation, than those which receive the sun's rays more directly.

The measure of the moisture of the soil gives most directly a knowledge of the supply available for the trees of any forest type. It has been shown, with the limited number of stations at which this measure has been taken, that the absolute amounts of moisture in the soil, during either the average growing season, or the driest part of an unusually dry season, are commonly greatest in the spruce sites and the north-slope Douglas fir sites. The yellow pine, limber pine, and lodgepole pine sites have considerably less. Only on strong southerly exposures, however, and near the lower limit of the yellow pine type, where good precipitation is experienced during the growing season, is the depletion of the supply very considerable, and even in these situations the wilting coefficients of the respective soils have not been closely approached at any time during the period of observations. In fact, the higher moisture percentages of the spruce and fir soils do not indicate much more favorable conditions for growth than the lower percentages in the pine types, because the soils of the latter class are always more sandy and hence such moisture as they retain is relatively more available for plants.

Nevertheless, the differences between the types in soil moisture content have a significant bearing. The fact that the minima reached in the various types are so similar in physiological value is in itself evidence that the density of the stand or number of individuals per unit area tends always to adjust itself to the average amount of moisture present, or perhaps even more closely to the absolute minimum amount reached during a long period of years. Therefore, even if the several species showed no differences in their moisture requirements or absolute drought resistance, the moisture content of the soil would strongly influence the character of each forest type by limiting the density of the stand, and thereby affecting the insolation, the evaporation, the soil temperature, and all other contions of the forest floor, which in turn influence the character of the reproduction. This only shows how closely interrelated are the several conditions of the environment. The amount of insolation falling upon a site affects the conservation of the precipitation. The conserved water, by determining the density of the stand in turn, affects the amount of insolation, and so on, ad infinitum.

The important difference between the moisture conditions of the spruce sites at one extreme and the pine sites at the other is not so much in their absolute water contents, considering the entire soil reservoir of each as in the fluctuations of their surface conditions. The well-shaded spruce soil may become very dry at the surface when the atmosphere has been dry for a long time, but it does not dry out severely between the rather frequent summer showers.

Hence spruce seeds have ample time for germinating and are in no haste to extend their roots deeply, often only penetrating the humus layer and establishing contact with the mineral soil by the end of the first summer. The rapid drying of a well-insolated soil, on the other hand, demands prompt germination and rooting of the seedling. Yellow-pine seeds do not germinate more promptly than those of the other Rocky Mountain species, but the seeds are large, the seedlings large and strong, and the root is often extended 3 or 4 inches into the soil before the cotyledons appear above ground. Quite often the roots of yellow-pine seedlings must extend to a depth of a foot and below most of the grass and weed roots before a stable supply of moisture is assured.

In all probability moisture becomes an important factor in limiting the downward extension of the yellow-pine forest, though here we have no proof that excessive temperatures may not as often be the immediate cause of the death of seedlings. Moisture is probably controlling where other vegetation is already established; heat is probably controlling on denuded sites.

CONCLUSIONS.

Each site in the various forest types of a mountain region such as has been studied and reported in this bulletin by means of the several stations presents a unique complex of all the conditions which comprise the atmospheric and soil habitat. Two sites may not vary in a single one of the many conditions which are enumerated as wind, humidity, temperature, soil moisture, etc., without having some effect on the vegetation. In fact when the reproduction of a small forest area is studied in detail most surprising and often unaccountable differences in the number, size, and species of the seedlings growing thereon may be noted in different parts of the area, even though it be only a few yards in extent. It seems, therefore, almost hopeless to attempt to define every factor which is accountable for vegetation of a given type. The best that can be hoped for is that the maxima or minima, or, in other words, the extreme conditions of any nature which a given species will tolerate, may be depicted by a study of the present kind, or by a series of such studies properly correlated. To a limited extent this has been accomplished in the discussion of each factor and in the recapitulation. Since it is a common human desire to have complex matters made to appear simple a single generalization may be indulged in, as a kind of summary, after which the exceptions may be noted and the specific problems of each species may be defined as they are seen at this stage.

A review of the facts that have been presented leaves little doubt that the several tree species of the central Rocky Mountains are controlled in their distribution almost wholly by the degree of insolation of the site, the resultant temperatures, and the closely related surface moisture conditions.

In a general way the forest zones correspond with air-temperature zones, and the considerable differences between the air temperatures of north and south exposures at the same elevation might explain the corresponding differences in the forest types. However, even when air temperatures are measured close to the ground, the critical differences between sites are not brought out. Air moves so freely from

one point to another that there can not be a great difference, for example, between a sheltered and an exposed spot on the same slope separated, say, by a distance of 50 feet. Yet it is obvious that the insolation received on the one spot must have the greatest possible influence on the critical conditions for the regeneration of forest trees. Therefore, although air temperatures do generally outline the types fairly well, one must conclude from certain important exceptions that they reflect rather than define the controlling conditions.

The study has shown not only that soil temperatures at a depth of 1 foot bring out more clearly the differences in aspect, which for denuded sites are fully as great as the differences resulting from elevation, but also that the correlation between soil temperatures and the reproduction of the several species is closer than that between air temperatures and species. The meager data on surface-soil temperatures that are so far available indicate that the differences between sites which encourage different species are far greater than might be thought possible—at least three or four times as great as the differences between temperatures at a depth of 1 foot. To use again the example taken above, the spot on a north slope which receives full insolation for two or three hours in the middle of the day may have surface maxima 20° to 25° higher than the nearby sheltered spot, and a similarly exposed south slope may attain surface temperatures 30° to 40° higher still. The surface temperatures on south slopes, moreover, occasionally attain to 150° F., a temperature which, it is believed, is likely to be fatal to any young plant, independent of its drying effect on either plant or soil.

The influence of direct insolation in drying the surface of the soil is hardly less potent than its temperature effect in demanding special adaptations of the plant. Again, direct insolation plays an important part in keeping moisture available to both young and old trees during the winter season, when it is likely to be completely withdrawn through the freezing in the soil.

A frank consideration of the weak as well as the strong points in the evidence which has been adduced in "Physiological Requirements of Rocky Mountain Trees" (*6*) and in the present bulletin, compels the making of somewhat tentative conclusions as follows:

(1) Western yellow pine is not a conservative user of water, nor is it efficient in photosynthesis. It is deduced from this inefficiency that it may thrive best in full sunlight and a warm atmosphere. There is certainly nothing in the evidence to suggest that it prefers a dry to a moist soil. However, its seedlings have the habit of rooting promptly and deeply, a habit which has doubtless been developed because of the need of the species for a warm situation whose surface soil dries out quickly. It may, then, be said unequivocally that yellow pine seeks the warmest sites at middle and low elevations, because of their warmth. With yellow pine at least, the evidence is convincing that warmth of the soil in winter, and availablity of moisture, is a necessity throughout the life of the tree.

At its lower limit yellow pine may come into competition with piñon, or with grasses and other low plants whose life cycle is completed in the short period of most favorable moisture. Little is known regarding piñon, but it is the writer's belief that this pine subsists on a smaller water supply than yellow pine, and also that it is much less sensitive than yellow pine to the high salt concentrations which are

encountered in the poorly-watered and largely unleached soils of the foothills.

(2) Douglas fir is often in close competition with yellow pine through much of the altitudinal range of the latter. Douglas fir is undoubtedly more "tolerant" of shade than the pine, is more effective in photosynthesis, and uses less water. Douglas fir seedlings root almost as deeply as those of yellow pine in the first few weeks of life; but fir seedlings are quite evidently more subject to directly injurious effects from high temperatures, than are yellow pine seedlings of equal age. Therefore, it is apparent that Douglas fir can tolerate almost the same condition as yellow pine, and on a soil containing sufficient moisture to support a moderately dense stand, Douglas fir may be the better tree because of its greater photosynthetic capacity, and may eventually dominate the pine. But there is no point in the field evidence clearer than the fact that Douglas fir seedlings will not tolerate full sunlight on a slope where its heating effect is greatest. Therefore, the fir can be a pioneer only on northerly aspects or in the shade of such objects as boulders.

It would appear to be misleading to assume, in any instance, that fir replaces pine as a direct result of favorable moisture conditions. Conditions may be conceived in which great moisture would so modify the surface temperatures as to make possible fir reproduction in full and direct sunlight, but under the conditions of the present study the moisture factor is effective only through the production of canopies and shade.

(3) Engelmann spruce is even more effective in photosynthesis than Douglas fir and uses its water more economically. The seedlings of spruce, however, are very slow in placing their roots at a depth, seeming to prefer the surface layer of the soil and to branch considerably in this layer. This is puzzling in view of the extreme dryness which is sometimes attained by a surface layer composed almost wholly of only partly decomposed litter. It is possible, however, that the roots do penetrate to the top of the mineral soil, with its more certain moisture, and that the seedlings are satisfied with the small supply of moisture insured by this. Another puzzling fact is that spruce seedlings appear to be less easily injured by excessive temperatures than seedlings of Douglas fir, although when drying becomes a factor, the reverse is true.

From the present evidence the conclusion is plain that Engelmann spruce occupies its cold sites and high elevations purely because of a superior ability to grow with less direct light and with lower temperature than are required by any of the other species. Again it is misleading to speak of the direct effects of moisture as a determinant, except in the sense that spruce seedlings are evidently not adapted to situations in which the surface soil dries quickly. There is, however, another soil factor which the writer believes to be very important, and concerning which, it is hoped, convincing evidence may be presented within a short time. This is the factor of chemical composition of the types of soil commonly claimed so exclusively by spruce or perhaps, to use a more familiar term, the factor of soil acidity, although it is the present belief that spruce is equally tolerant of high acidity and strong alkalinity. Without doubt, in some instances, it is the chemical conditions of the soil, rather than moisture contents or light conditions, which draw a sharp line between spruce and Douglas fir forests.

(4) Lodgepole pine is little, if any, more efficient in sunlight than yellow pine, but appears to be more conservative of its water supply. The seedlings are as frail and shallow rooted as those of spruce, so that they do not tolerate drying conditions. On the other hand, the direct effect of heating seems to be less injurious with lodgepole pine seedlings than with those of yellow pine, Douglas fir or spruce. An additional factor in the life of lodgepole is the very sluggish germination of its seed except when stimulated by frequent and wide ranges of temperature, as, for example, a daily range of 30° or more. This characteristic appears to be the outgrowth of repeated regenerations on open ground, where the temperatures are not modified by cover of any sort, or perhaps are augmented by such an absorbent as charcoal. In fact, every quality of lodgepole associates the tree with pioneering in completely denuded ground. Even the slow rooting of the seedlings may be seen to be adapted to a soil in which there is no competing vegetation, and whose moisture has been made more accessible by the destruction of the surface humus. But obviously this slow rooting would be a very unfavorable characteristic in an open situation where the surface moisture was not frequently replenished by showers, or where it was very effectively dissipated by insolation, as in typical yellow pine sites.

Clements (*10*) has rendered a distinct service to students of forestry by picturing vegetation as being constantly in a state of development or flux as the result of changes in the site conditions and because of the competition between species with different qualifications. In somewhat the same vein, it may be best, since it has been shown that the composition of any forest type is very much a matter of competing elements, to consider now the typical situations which have been studied at one or more stations, each in its ensemble, with the hope of destroying any narrow or incomplete view which has been created by considering the physical factors singly. This should be done with the fact clearly in mind that the important differences between sites arise almost wholly from differences in insolation. Otherwise a very poor conception of causes will be obtained.

(1) *A steep south slope at middle elevation.*—The gradient is such that at midsummer the sun's rays fall almost normally on the surface. The insolation may be rated as unity. As the resultant surface temperatures are very high, frequently reaching 140°, and occasionally 150° or more, young succulent vegetation on the surface of the ground might be almost instantly killed. There is an almost complete lack of annual herbs. The rate of evaporation is very high. This rate may be expressed as unity. The soil is almost lacking in humus. The surface dries quickly after showers, but owing to the unbroken mineral soil, capillary action ordinarily keeps a reasonable amount of moisture near the surface. The soil has poor holding capacity because of the lack of humus and also is lacking in nutrient salts. Consequently, it can never support heavy vegetation. At the outset only the sturdiest of seedlings can survive. If they start after midsummer, they must develop rapidly both as to root and lignification, in order to be prepared for the critical conditions of the next season. A freely transpiring species is required, for transpiration may protect the tender leaves from superheating as perspiration protects the bodies of some animals. The ground will not freeze permanently if at all; hence the seedling need not be inherently drought resistant,

that is, of high sap density. Yet deep rooting is essential in order that any adequate supply of water may be had, and later extensive rooting must be developed in order to insure the supply of water from a soil of such meager capacity.

Either yellow pine or limber pine fits these conditions. The large seed of either species is a fairly good guarantee of the vigorous initial growth that is essential. Later, when the pines make shade, an occasional Douglas fir may become established in the most shaded spots. Limber pine will disappear if the stand becomes at all close, because it can not compete with yellow pine in growth rate or ultimate stature. Any species, with the possible exception of spruce, could be planted here if sturdy young trees were used, for the only really dangerous factor is excessive heat.

(2) *A flat ridge.*—The insolation is about 0.80 or 0.85. The highest surface temperatures reach 120° to 130°, but they are not prohibitive to tree establishment except as they induce rapid transpiration and soil-drying. The wind exposure is greater than on the south slope, and the evaporation is almost as high. Greater difficulty is experienced in forming any soil; all the humus is moved away and there is little chance for any to be deposited. The same is true of the finer particles of soil as the rocks break down; consequently there is practically no soil over the rock. Very little water can be retained. The forest must always be very open. The difficulties of initiation, however, are not so great as on the south slope. Limber and yellow pines predominate, but the yellow pines are lacking in vigor, being evidently exposed to some desiccating force they can not cope with. This is probably the winter wind. The insolation is not enough to keep the soil from freezing deeply, and the wind exposure is worse than on any other site except a westerly slope. Some Douglas fir seedlings appear, with a little protection, and they do not suffer from the winter conditions.

(3) *The middle of a north slope.*—In heating effect the insolation can not be rated over 0.50 at midsummer, and may dwindle almost to zero in winter. Hence the striking characteristics of the slope are ability to retain moisture and a long unbroken period of freezing during the winter. As measured just above the surface on a denuded site, the insolation and evaporation may at times be nearly of unit weight; but of course the evaporation may become negligible when the sun is very low. The conditions for soil building are almost ideal. On this kind of a site there is adequate heat and moisture for the early development of any species. The retention of a snow blanket in winter practically eliminates exposure and further encourages a mixture of all the species. Only spruce may at first be prohibited, and until other vegetation shades the ground and modifies the superficial drying of the soil.

The large quantity of moisture present encourages a heavy vegetation of all sorts and quickly changes the denuded site to a thicket. The later conditions are radically different from those which initiate the succession. Direct light, while not entirely wanting during the growing season, is at a premium. Only the species which are more effective in photosynthesis can develop properly. At first Douglas fir will predominate, simply because spruce was handicapped at the outset. In another generation without disturbance, the spruce will

be equally or more abundant. The disappearance of the yellow pine and limber pine which at the outset found the conditions favorable is a slow and almost pathetic process. They do not, except in infrequent years, suffer for lack of moisture; and as their crowns rarely appear among the dominants they do not even suffer the most severe winter drying, which is very rigorous for the tallest trees on this site. Unlike the suppression which is so common in crowded stands on less moist sites, which takes the form of complete stunting, the strictly shade suppression here results in putting all of the energy of the tree into height growth, the side branches being quickly eliminated, and no food being left for the proper strengthening of the stem. The result is a long, slender, supple pole, with only a tuft of green at the top, which is invariably a little lower than the tops of the surrounding firs. Limber pines and yellow pines which reach this stage are usually destroyed by snow breakage.

(4) *The foot of the north slope.*—The steepest portion of a slope is very commonly just below the middle. Further down, deposition of material from the upper slope may more than keep abreast of erosion. Hence the ground tends to flatten out, and frequently a bench is formed somewhat above the stream bed. For a considerable part of the year the site may be shaded by the steeper ground to the south. It receives by transport the best of the soil formed on the entire slope; very commonly it receives also the run-off from heavy rains and, with some rock formations, the seepage. There is, then, a greater water supply than elsewhere, a deep, spongy, retentive soil and little insolation to dissipate it.

Probably because such a site is a catch-all for seeds as well as for soil-building material, it can not long remain denuded. Rank herbs appear almost immediately, and tree seedlings rarely start except with the keenest competition for light. Year after year the herbs grow up about the seedlings, and there is at no time opportunity for any but the most shade-tolerant trees. Even these have a very long struggle before they eventually find "their place in the sun." The conditions, of course, do not change materially after a forest is established. There will always be a dearth of light. If the stand is very dense, in a protracted drought there may be a fairly complete exhaustion of the moisture as deeply as the roots penetrate. The most prohibitive condition, however, probably arises from the undisturbed accumulation of litter on the forest floor. After the snow has melted in the spring, and this loose, jack-straw mass has slowly dried out, it will in all probability not become wetted again until the next snow falls. Certain greenhouse tests made by the writer have indicated that the refusal of resinous needle litter to imbibe water creates a serious problem in connection with the germination of seeds. In consequence, a large part of the floor under spruce may be as barren as the desert, and it is especially with such conditions that the marked results of any soil disturbance, such as occurs through the skidding of logs, are to be noted in succeeding reproduction.

The description here given refers in a degree to the lower portions of all north slopes, and commonly to that portion of the stream bench contiguous thereto. It is, of course, evident, that in so far as the slope itself is short or moderate in gradient, it may fail to produce the depicted conditions at its foot, and under certain circumstances there may be no area in this position that would be prohibitive to

Douglas fir or even to yellow pine. The Black Hills in general, being "hilly" rather than mountainous, encourage yellow pine on all sites; but in the more mountainous portion, and where the erosion of sedimentary formations has resulted in long and steep slopes, the Black Hills spruce is found, as might be expected from this description.

In order to complete the picture of a valley cross-section, it is only necessary to add that, except in narrow canyons whose walls shade a great area, the creek bottom facing the south is likely to be of a very different character. That area which is not shaded when the sun is highest will immediately take on the character of the south slope, as described in paragraph 1, with this important exception, that the soil deposition, seepage, and run-off which this area may receive, may encourage a denser stand than characterizes the upper slope, and in this denser stand it is not uncommon to find stragglers of the more tolerant Douglas fir, and even of spruce.

(5) *The east slope at middle elevations.*—As has been clearly shown, the east slope in the Pikes Peak region receives a large proportion of the direct insolation, for the simple reason that the mornings in summer are generally cloudless. This means that surface temperatures may be attained almost, if not quite, as high as on south exposures, it being understood that the maximum effects of insolation are approached very quickly. This direct insolation is, however, of less duration than on south slopes, and its drying powers are proportionately less. The evaporation may be rated between 0.70 and 0.80. The result is of course a better conservation of moisture. This is without doubt augmented by a fairly good soil, built up by the wind deposits of material from west exposures.

The existence of direct insolation, creating excessive temperatures in the morning if only for a short time, means that the pioneer trees must be largely yellow pines. The conservation of moisture however, permits heavier stands than can be supported on south slopes. The result is that on easterly exposures the succession of pine by Douglas fir is more prompt and more certain than on south exposures.

Under certain conditions there may even be no pine stage. A good illustration is that of an extensive east slope below a middle elevation, which after being denuded by fire produced directly a heavy stand in which fir is much more prominent than yellow pine. This entire slope, however, is boulder-strewn, and these boulders perform the same function as pine trees; that is, they supply the necessary shaded spots for fir seedlings. The boulders are much to be preferred to pines as nurses, because they use no water. This phenomenon may occasionally be noted even on south exposures.

(6) *The west slope.*—The winter winds make this aspect by far the most difficult of any at middle elevations to cover with vegetation of any sort. A west slope does not in the aggregate receive so much insolation as an east slope, yet on exceptionally clear summer days it may easily become very warm, and is with certainty fitted only for the limber pine and yellow pine. In summer the evaporation rate is moderate, and the moisture conservation would be good were there any soil to retain it. In winter the evaporation rate is nearly as great as on a south exposure. Probably a more severe strain is presented here because the soil is thawed much less frequently. Along with the desiccating effects of the west wind, which is a factor only in

winter, must of course be mentioned its ability to remove the soil-building materials.

The physiological studies have indicated that limber pine is as low as yellow pine in photosynthetic capacity, and perhaps lower; yet a more important factor in its distribution is the probable fact that it never exposes itself to rapid water losses through the stomata. Lacking the vital qualities which make our forest trees what they are, this weed is apparently satisfied to "close up shop" whenever the conditions are in the least unfavorable, and thereafter it is practically immune to desiccation by wind. It is for this reason that limber pine becomes established on west slopes where yellow pine can not. Although it is a valuable pioneer, it is intrinsically so worthless that its tenure might well be temporary. Unfortunately, a cover of limber pine on a westerly slope is usually scant, and neither the wind exposure nor the insolation is very much modified thereby. So far as the writer's observation goes, only spruce may be expected to supplant the limber pine, and this probably so slowly that centuries may be consumed in the succession.

(7) *Lower elevations.*—The general relationships among the six sites described above, must of course prevail at any elevation. The fact of the matter is, however, that even when, topographically speaking, these sites are duplicated near the foot of the mountains, the conditions are found to be very different. At the foot of the mountains there is less precipitation; higher temperatures prevail the year round, tending further to dissipate this precipitation; the atmosphere is relatively drier at the eastern foot; and perhaps most important, the higher air temperatures further augment insolation in producing unbearable conditions at the surface of the ground. To a certain extent these higher temperatures must be counterbalanced by weakened light intensity.

The effect of less precipitation and its more rapid dissipation must of course be to make impossible on any site such dense stands as prevail at higher elevations. When to the greater openness of stands is added the greater heating opportunity per unit of area, it is readily seen why there should be, first, the entire elimination of the heat-sensitive Englemann spruce, with Douglas fir occupying the most sheltered sites, then the confinement of the forest to northerly aspects, and finally its disappearance where the mountains merge into the plains.

It is not necessary or relevant to do more than mention blue spruce (*Picea parryana*), white fir (*Abies concolor*), or piñon pine (*Pinus edulis*), which are evidently more heat-tolerant than their mountain counterparts and succeed in slightly extending the group ranges. These trees have little place in the economy of the forest and have been given no careful study.

There is not much question in the writer's mind that soil quality is an important factor in the sudden termination of the forest at low elevations. Not only in the Pikes Peak region but generally throughout the Rockies, the mountains proper are composed of igneous rocks and the foothills of sedimentaries. The former produce open, more or less gravelly, well-drained soils, the drainage being further insured by the strong relief. The sedimentaries produce fine, compact soils; and as the foothills are almost invariably devoid of springs and permanent streams it is evident that their soils are rarely subjected to

leaching. Such soils are much more fertile than the mountain soils; but if they were equally moist at all times they would still present a more arid condition in the physiological sense. There are still two other aspects to the matter. The fine, compact soils, when rain is withheld, dry out more completely and more deeply than mountain or sandy soils; consequently they may be not only more arid but more liable to super-heating. Again, when the plain is reached the stability of such soils precludes any denudation and permits the firm establishment of perennial grasses; consequently competition alone would preclude the establishment of tree seedlings.

When, therefore, the question is raised whether it is lack of precipitation or heat which excludes the coniferous forests from the plains, the answer may be given unequivocally that it is both, and that it is also alkalinity of soils and competition. It is nature's unanimous verdict. Yet it is to be noted that with the possible exception of alkalinity, none of these conditions need absolutely inhibit tree growth. For this reason, wherever there is a reasonable amount of relief and nature has had extreme difficulty in establishing tree seedlings, planting may still be conducted with a high degree of success.

(8) *Higher elevations.*—On the several sites at higher elevations there is greater light intensity, modified in its effects by lower air temperatures and increased precipitation and conservation. It would seem, therefore, that the conditions were exactly the opposite of those at low elevations. However, there is an important exception in the fact that wind movement in the higher atmosphere is much freer than near the general surface of the earth, and there is no site at high elevations which is entirely free from this added wind effect. This tends to make the evaporation rate relatively high.

Because the coolness of the air is largely, if not fully, compensated by greater intensity of the sunlight, it is not surprising to find that our light-demanding pines invade denuded areas, yellow pine to an elevation of 10,000 feet and limber pine up to timberline. About where yellow pine fails bristlecone pine may be expected to take its place.

Quite different, however, is the behavior of Douglas fir, which in the Pikes Peak region is not seen much above 9,300 feet elevation. Apparently there is no place for this species where conditions are so readily made suitable for spruce by a minimum amount of shade. It is not the intention to say that in an early stage of succession there is no favorable place for Douglas fir but rather that in the final stage there is no place, and having been crowded out of the last climax forest it has been unable to retrieve its position since the fire that occurred about 60 years ago.

At the higher elevations the completely denuded areas are invaded by yellow pine, limber pine, and bristlecone pines; but, with the possible exception of a few rocky ridges incapable of supporting many trees, every site whose elevation is more than about 10,000 feet must eventually be conquered by spruce. On much of the area no other conifer is found. A quick growth of aspen sprouts after a fire is possible on almost any site, and these form abundantly heavy shade for spruce seedlings.

(9) About lodgepole pine sites, which do not exist in the Pikes Peak region, it is necessary to say a word because of the close relation of lodgepole pine in many localities to the more valuable species.

This species, like the other pines discussed, is evidently light-demanding; but, unlike the other pines which through long ages have adapted themselves to the surface drying which results from direct insolation, the germination of lodgepole seeds is slow, and the development of root in the young seedling is feeble. For this reason lodgepole commonly reproduces on fully insolated sites only where there has been complete denudation, as by fire, and where its moisture supply is made as certain as possible by the destruction of its competitors. More frequently than not, mature lodgepole stands are so open as to give plenty of light for germination; but as the open stand results from limited moisture it follows that the seedlings may develop only very slowly and may be wiped out in drought years. The greater the moisture and the denser the lodgepole stands, the more certain it is that spruce seedlings rather than lodgepole will predominate in the reproduction, and that the ground can be regained for this more valuable tree. On the other hand, on drier ground which probably once belonged to Douglas fir, there may be much less opportunity for the fir to take possession primarily because of its very inferior seeding capacity. For this reason much of the ground in this region which is capable of supporting high-quality fir stands will be very slow in returning to that species.

That lodgepole pine is almost completely absent from the immediate territory of this study appears to be due to a dry atmosphere, a loose, rapid-drying surface soil, and hence less favorable conditions for germination than it demands. On sites where the conditions for germination might be favorable, it is possible that soil freezing may be prohibitive. The growth of lodgepole trees planted on yellow-pine sites in the Pikes Peak region has been excellent, but establishment by direct seeding has been accomplished only in a few favored, though warm, spots.

APPLICATIONS.

The value of a more exact knowledge of the forest trees with which we are dealing in the National Forests of the central Rocky Mountains should be evident to anyone at all familiar with the problems of forestry. To what extent knowledge of any fact may affect human plans and activities can never safely be prognosticated. Yet it is safe to point out some of the benefits that may be had immediately as a result of facts brought out by this study or previously discovered and, perhaps, confirmed by the large amount of data here presented. It is necessary, of course, to refrain from generalizing; yet it must be apparent to foresters in other regions that in each forest region there are counterparts of the species here discussed. It may, therefore, be helpful to understand the relations between species as they have here been depicted.

Neither the physiological investigations nor the field data secured in the present study indicate any marked difference between the species in actual drought resistance; and by this is meant ability to extract water from the soil when the condition of physiological dryness is being approached. If there is any such difference, it is theoretically in favor of the species which are commonly thought of as demanding moist sites, but which in reality demand cool sites, namely, spruce and fir. On the other hand, a species like spruce which is accustomed to moist, rich soils and develops a compact root

system, may be able to drain the moisture of the soil more completely, because from the outset its roots are more finely divided, and they more completely reach all of the moisture. The tree accustomed to a dry soil insures its moisture supply by reaching into an extensive area.

There has been shown to be, however, a very great difference between the species in photosynthetic efficiency, in ability to utilize whatever of light may be available, in sensitivity to high temperatures and drying which may result from direct insolation, and, finally, in the efficiency with which water is used. The relations of the several species to light are important silviculturally. The fact that one species may utilize 10 per cent of the energy of incident sunlight in the production of carbohydrates, and 90 per cent in the wasteful evaporation of water, while another utilizes only 5 per cent of the energy of incident sunlight, is of the vary greatest importance economically. The species which nature has developed to serve as the climax of any forest succession is the most highly developed plant organism of that association, and in all probability is the species which may most fully serve human needs, at least in the sense of quantity production. For a great many regions, as well as for the one here discussed, this species will probably prove to be spruce.

The most obvious application of the results of this study is that in the reforestation of denuded areas or the afforestation of such areas as our sand-dunes, it is possible to advance nature's process by at least one successional stage. For example, a denuded, strongly insolated site, which is known to have borne in the past a stand of Douglas fir, but which, from direct or indirect knowledge it is known will first be stocked with pine, is under no necessity whatever to go through the pine stage. The area may be immediately stocked with fir, with very great assurance of success, because the 3-year-old trees which may be planted are not susceptible to the heat and drought of the site which would be fatal to young seedlings. To a certain extent, on the same basis, a given species may be planted on a somewhat lower, warmer, and drier site than would naturally, at the same stage, reproduce that species.

Not only are these things possible in reforestation, but they are obligatory upon foresters, in order that the land may be put to the highest use, and the moisture, almost always limited in quantity, may be utilized by the most efficient of the organisms capable of existing under the given conditions. Exception must of course be made where a certain species is most desirable for its technical value.

In the management of forests for continuous production, which always implies the securing of natural reproduction, the realization that the nature of the reproduction secured will depend almost entirely on the conditions of insolation must be very helpful in determining the weight and character of the cutting. It should be kept in mind that, while the cutting of undesirable species may reduce the number of seedlings of that species which will appear, it is no guarantee whatever as to the identity of the seedlings that shall survive. That will be determined by the light and heat conditions which result from the cutting in the aggregate. In general, all cutting in climax forests must tend to encourage the species of the successional order next below the climax, and in clear cutting the result may be a reversion of two or three stages. The maintenance of the climax forest may

be anticipated only by very light cutting, except of course in the upper spruce zone where there are no subclimatic trees.

In the lower part of the spruce zone, too heavy selection cutting is almost certain to encourage Douglas fir seedlings where that is the species next in order, and lodgepole in the region where this tree has invaded the Douglas fir and lower spruce zones.

Much of the lodgepole forest would be replaced by spruce, and other portions by Douglas fir, if the lodgepole were left uncut or were thinned very lightly. The heavier the cutting, the more certain it is that lodgepole pine will continue to hold the ground.

Nearly all of the Douglas fir forest of the central Rockies, if cut too heavily, is subject to invasion by western yellow pine or the worthless limber pine. However, on northerly exposures, there is much less danger of this, and a heavy cutting under the shelter-wood plan appears most likely to give prompt and desirable results.

As the less severe yellow-pine sites will in the natural sequence of events go over to Douglas fir, there is no very evident reason why Douglas fir seedlings should not continue to come in with the protection of their parents only, if it should seem desirable to remove the yellow pines, provided only the stand is not too greatly opened. A much more serious problem is presented in the lower portion of the yellow-pine type, where the stands are always so open as to permit the formation of sod, and where any new opening may be quickly occupied by the perennial grasses. Silvicultural caution demands that cutting be done only when there is a seed crop. A favorable year following can of course never be guaranteed. Evidence in the Southwest to the contrary notwithstanding, the writer is firmly convinced that the perpetuation of the mountainous yellow-pine forest in this region can best be insured by the burning of the brush in piles, a measure which, as everyone knows, eliminates the grasses for a period of several years and gives the pine seedlings at least an equal opportunity with other vegetation.

On the general subject of brush disposal this study appears to have offered only one other suggestion. It is believed that, where spruce forests grow on moderately steep to very steep slopes, both the nature of the ground and the relative openness of the stand prevent excessively heavy accumulations of needle litter, which, an attempt has been made to show, may afford a very unfriendly seedbed. On such slopes there is likely to be advanced reproduction, and burning of the brush is neither called for nor desirable. On the contrary, on flats which usually produce the most superb spruce forests, very serious delay of reproduction is likely to result, even after heavy cutting, unless some spots are laid bare. Furthermore, the accumulation of litter should by no means be added to. Here the burning of brush is distinctly called for. There is some evidence that this may also reduce the percentage of alpine fir (*Abies lasiocarpa*) seedlings, which are more vigorous than spruce seedlings and establish more certainly in deep litter.

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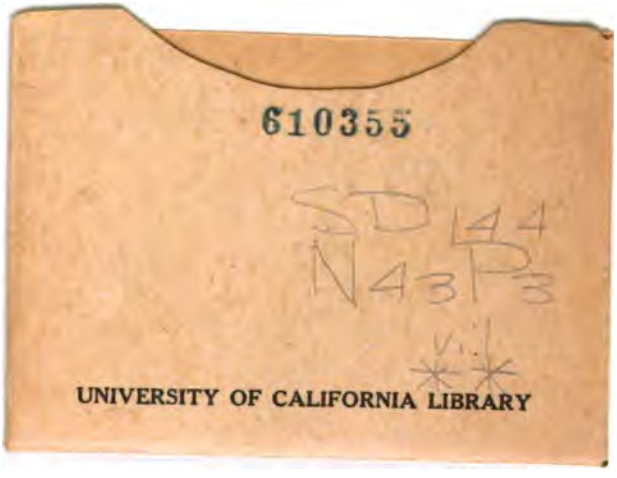
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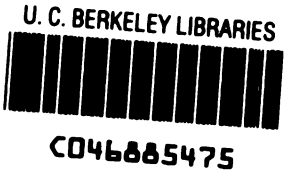
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